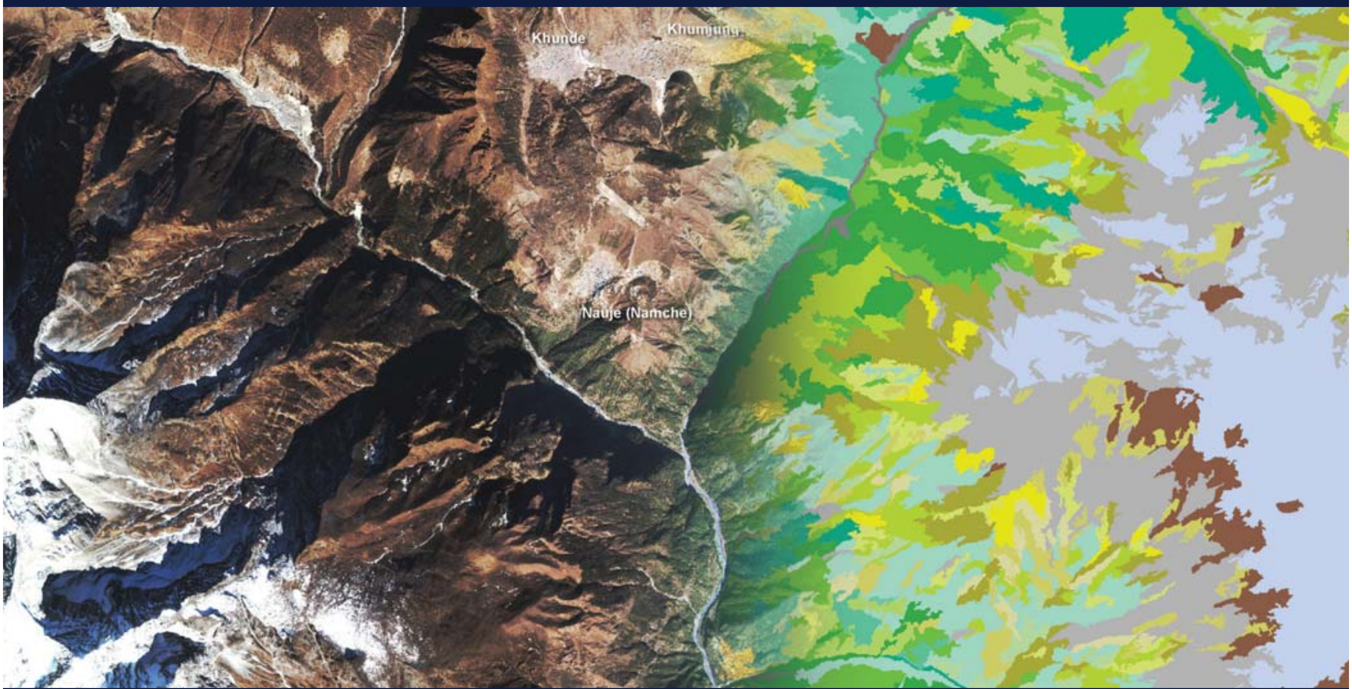
HKKH Partnership
for ecosystem management

Land Cover Mapping in the HKKH Region

Cases from Three Mountain Protected Areas



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Institutional Consolidation for the Coordinated and Integrated Monitoring of Natural Resources towards Sustainable Development and Environmental Conservation in the HKKH Mountain Complex

About ICIMOD

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Cases from Three Mountain Protected Areas

Birendra Bajracharya, Kabir Uddin and Basanta Shrestha

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Cover:
Land cover map overlaid on IKONOS image showing Namche and Khumjung area in Sagarmatha National Park and Buffer Zone, Nepal.

Acronyms

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CAS	Chinese Academy of Sciences
CESVI	Cooperazione e Sviluppo
CKNP	Central Karakoram National Park
DEM	Digital Elevation Model
Ev-K2-CNR	Committee for High Altitude Scientific and Technological Research
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information System
GLC2000	Global Land Cover 2000
GLCN	Global Land Cover Network
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
ICIMOD	International Centre for Integrated Mountain Development
IGBP-DISCover	International Geosphere Biosphere Program - Data and Information System Land Cover
IGSNRR	Institute of Geographic Sciences and Natural Resources Research
IUCN	International Union for Conservation of Nature
LCCS	Land Cover Classification System
MODIS	Moderate Resolution Imaging Spectroradiometer
NDSII	normalized difference snow and ice index
NDVI	normalized difference vegetation index
NDWI	normalized difference water index
NOAA-AVHRR	National Oceanic and Atmospheric Administration - Advanced Very High Resolution Radiometer
QNNP	Qomolangma National Nature Preserve
SNPBZ	Sagarmatha National Park and Buffer Zone
SPOT	Systeme Pour l'Observation de la Terre
UMd	University of Maryland
UNEP	United Nations Environment Programme
WWF	World Wildlife Fund

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Executive Summary

The “Institutional Consolidation for the Coordinated and Integrated Monitoring of Natural Resources towards Sustainable Development and Environmental Conservation in the Hindu Kush-Karakoram-Himalaya Mountain Complex,” or the HKKH Partnership project supports the development of institutional capacities for systemic planning and management of mountain resources at local, national and regional levels. The project is implemented by International Union for Conservation of Nature (IUCN), International Centre for Integrated Mountain Development (ICIMOD), Ev-K2-CNR Committee and CESVI. The project is a multi-scale initiative, working at regional, national and local levels with a special focus on three protected areas: Sagarmatha National Park and Buffer Zone (SNPBZ) in Nepal, Central Karakoram National Park (CKNP) in Pakistan and Qomolangma National Nature Preserve (QNNP) in Tibet Autonomous Region (TAR) of China. The project initiated the concept of the Decision Support Toolbox (DST) as a collection of participatory and adaptive approaches to support decision-making. This requires an understanding of the social and ecological processes and land cover dynamics is an important aspect that provides valuable insight on the evolution and changes occurring in the ecosystems. Land cover is a fundamental variable that impacts and links many parts of the social and physical environments, and is used as baseline information for planning, monitoring and evaluating development interventions. An assessment of existing spatial data for all the three project areas revealed that recent data on land cover missing. Therefore, developing data and analysis of multi-temporal land covers was given priority.

A review of land cover initiatives at global, regional and national levels was carried out. Land use and land cover changes have been extensively researched at the macro level due to its key role in environmental goods and services. Datasets for land cover detection and mapping at the global level are available on a daily basis mainly from three satellite sensors: National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer (NOAA AVHRR), Systeme Pour l'Observation de la Terre (SPOT) VEGETATION and Moderate Resolution Imaging Spectroradiometer (MODIS). Along with the availability at the global level from various satellites, many legends and classification methods for global land cover have been developed.

International Geosphere Biosphere Program Data and Information System Land Cover (IGBP-DISCover), University of Maryland (UMd) Global Land Cover, Global Land Cover 2000 (GLC2000) and MODIS land cover data are freely downloadable and are widely used by the international science community. The analysis of these four global datasets shows that while these datasets in many cases are in agreement in terms of total area and general spatial pattern, there is limited agreement on the spatial distribution of the individual land classes. If global datasets are used at a continental or regional level, agreement in many cases decreases significantly. A review of past enumerations on land use and land cover types from the HKKH region showed that the legends are mainly manifested by the vegetation and land cover types and the objective of the respective work.

The three protected areas of project intervention vary greatly in spatial extent and the land cover mapping activities are targeted to be useful for applications at different scales. The project adopted a multi-scale approach in land cover mapping that will be useful in understanding the linkages at different scales. Therefore it was important to have a land cover mapping system that allowed aggregation at different level of details. The project adopted Land Cover Classification System (LCCS) methodology that has been developed by FAO/UNEP in order to cope with the growing requirement of accessing the reliable and standardized information on land cover and land cover change analysis. The LCCS standard is a comprehensive and standardized a priori classification system designed to meet specific user requirements and created for mapping exercises independent of mapping scale, land cover type, data acquisition method or geographical location. The project developed linkages with Global Land Cover Network (FAO/GLCN) and organized workshops in Nepal and Pakistan, focusing specifically on the needs of harmonizing land cover classification within the project framework. A 3-day training workshop was held from 11-13 April 2007 at ICIMOD bringing together professionals working on ecosystem and land cover studies. The participants worked on developing a preliminary legend to be used for the development of the land cover map of SNPBZ. A similar workshop was organized in Gilgit from 31 October to 1 November to introduce the stakeholders in CKNP to the LCCS concepts and methodology. Based on the recommendations, a draft legend for CKNP was developed and was further refined for classification of land cover after the field work.

The project adopted the approach of object-based image analysis for land cover classification. Object-based image analysis is coming up as a promising methodology in automatic information extraction and gives significantly better classification results.

Unlike the conventional pixel-based methods that only use pixel values, the object-based techniques can use spectral features as well as texture information, neighborhood information, context information, and other related ancillary data to gain higher accuracy of land cover mapping. Different parameters such as normalized difference vegetation index (NDVI), normalized difference snow and ice index (NDSII) and normalized difference water index (NDWI) are also used for better classification of vegetation types, soils, river, lake, snow and ice. Segmentation creates image objects containing information about their spectral characteristic, shape, position and texture as well as information about their neighborhood. Image objects are generated based upon several adjustable criteria of homogeneity. After a satisfactory segmentation, classification is carried out by associating image objects with an appropriate class. Different classes are related and arranged in semantic groups, which represent knowledge. This structure of knowledge representation allows automated image analysis. After the classification, the result is checked for accuracy and the steps are repeated if necessary. The areas that are smaller than the defined minimum mapping units are eliminated. The standard codes and LCCS labels are imported and the topology is updated to produce the final land cover map.

The land cover maps for all the three protected areas - SNPBZ, CKNP and QNNP - are generated using these similar methodologies. However, different image data are used according to their suitability and availability in the context of these areas.

In case of SNPBZ, the participants of the workshop on LCCS methodology held in Kathmandu worked to come up with preliminary legends depending on the different types of vegetation present there. A field mission was carried out to collect samples for image interpretation and classification as well as to refine the legend. The legend was finalized after several iterations. The detailed land cover map was generated from interpretation and classification of the IKONOS images of 2001. Although in terms of the area, the IKONOS image covered about 53% of SNPBZ, it covered all the area below 4,500 m elevation and therefore included almost all the vegetation areas. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) image from 2006 was used to generate the latest land cover map. The LandSat TM from 1992 and LandSat ETM+ image from 2000 were used for generating the past land covers for studying the changes.

A draft legend for land cover classes of CKNP was developed during a consultative workshop held in Karakoram University in Gilgit. The land cover mapping activity was carried out in collaboration with World Wildlife Fund (WWF) - Pakistan. The legend was further modified after the detailed field visit. An extensive field survey was carried out throughout CKNP in June 2008 using LCCS data encoding forms and GPS receivers. Due to the large area of CKNP, three teams were formed to survey the three representative areas, namely Bagrot Valley, Astak Nullah and Shigar Valley.

Level 1A ASTER satellite images from 2006 were used for the mapping.
The land cover mapping of QNNP was carried out in collaboration with Institute of Geographic Sciences and Natural Resources Research/Chinese Academy of Sciences (IGSNRR/CAS) which has been involved in many past research activities in Tibet. Reference data such as land use map of Xigaze, grassland type map of Xigaze, vegetation map of TAR, books and materials of scientific expeditions, and topographic maps at scale of 1:100,000 etc. were collected. A field mission to QNNP was carried out between 3 October and 2 November 2008 to collect samples for image interpretation and the validation of the land cover classification as well as to refine the legend. Advanced Wide Field Sensor (AWiFS) and ASTER images were used for the land cover mapping. ASTER image covered the area adjacent to and approximately equal in size to SNPBZ while AWIFs covered the whole QNNP.

The efforts made by the project in harmonizing land cover mapping in its three pilot sites have initiated the process of generating awareness about the concepts and developing capacities on common tools for the conservation and management of protected areas. The regional and national workshops brought together scientists and professionals from three project sites and many diverse fields - forestry, agriculture, ecology, natural resources, biodiversity and conservation - and changed the traditional approach of considering land cover mapping from the perspective of forestry alone. The emerging image analysis technologies have made it possible to assess the land covers more quickly, efficiently and accurately. The adoption of object-based image analysis has helped in improving the classifications. The methodology is being extended to other applications within ICIMOD and its partner institutions. Apart from using LCCS at the project level, the effort to build consensus at the regional level to develop a harmonized and standardized land cover are currently in the developing process. ICIMOD has already joined hands with FAO/GLCN to develop an institutional framework in this regard. The national organizations in the region have started working together and the technical resources required for this initiative has already been allocated through a regional workshop held in Kathmandu in 2008. The next step would be to build the capacity of the national partners to carry out this task at the national levels. This will pave the way for a harmonized land cover mapping of the whole HKKH region.

1

Introduction

Background

The regional project "Institutional Consolidation for the Coordinated and Integrated Monitoring of Natural Resources towards Sustainable Development and Environmental Conservation in the Hindu Kush-Karakoram-Himalaya Mountain Complex" (also known as HKKH Partnership project) supports the development of institutional capacities for systemic planning and management of mountain resources at local, national and regional levels. The project is implemented by International Union for Conservation of Nature (IUCN), International Centre for Integrated Mountain Development (ICIMOD), Ev-K2-CNR Committee and CESVI. The project is a multi-scale initiative, working at regional, national and local levels with a special focus on three protected areas: Sagarmatha National Park and Buffer Zone (SNPBZ) in Nepal, Central Karakoram National Park (CKNP) in Pakistan and Qomolangma National Nature Preserve (QNNP) in Tibet Autonomous Region of China.

The project initiated the concept of the Decision Support Toolbox (DST) as a collection of participatory and adaptive approaches with the aim of addressing the needs of different stakeholders to support key components of the decision-making. This requires an understanding of the social and ecological processes of the mountain protected areas. Land cover dynamics is an important aspect that will provide valuable insight on the evolution and changes occurring in these ecosystems. In fact this information will be essential in carrying out the analysis required to develop a systemic model of the target ecosystems. Therefore study of land cover and its dynamics was identified as an important activity of the project.

The pace, magnitude and spatial reach of human alterations of the Earth's land surface are unprecedented. Changes in land cover (biophysical attributes of the earth's surface) and land use (human purpose or intent applied to these attributes) are among the most important reasons for such alterations (Turner et al. 1990, Lambin et al. 1999, Di Gregorio 2005). Land-use and land-cover changes are so pervasive that, when aggregated globally, they significantly act on key aspects of Earth System functioning. They directly impact biotic diversity worldwide (Chapin et al. 2000, Sala et al. 2000) and contribute to local and regional climate change (Chase et al. 1999) as well as to global climate warming (Penner 1994, Houghton et al. 1999). They are the primary source of soil degradation (Tolba et al. 1992) and, by altering ecosystem services, affect the ability of biological systems to support human needs (Vitousek 1994, Vitousek et al.1997). Such changes also determine, in part, the vulnerability of places and people to climatic, economic or socio-political perturbations (Kasperson et al. 1995). Land cover change is regarded as the single most important variable of global change affecting ecological systems (Vitousek 1994). Land cover is a fundamental variable that impacts and links many parts of the social and physical environments and is used as baseline information for planning, monitoring and evaluating development interventions.

An assessment of existing spatial data for all the three project areas was carried out in the beginning of the project. From the preliminary assessment, it was realized that recent data on land cover is missing. Therefore, developing land cover data and analysis of multi-temporal land covers was given priority. A plan for development of land cover data was formulated accordingly with the following steps.

- Review of land cover initiatives at global, regional and national levels
- Detailed assessment of existing land cover legends
- Development of legend for land cover classification following the standards
- Acquisition/collection of satellite images of different dates
- Field work for sample data collection
- Interpretation/classification of images at different dates using the new legend
- Validation of classification
- Land cover change analysis

Land cover mapping at global and regional levels

Land use and land cover changes have been extensively researched at the macro level (Lambin et al. 2001) due to its key role in environmental goods and services. The large-scale results show that, due to increasing deforestation, forests are rapidly decreasing even as farmlands are extending. However, if the research is measured by a different scale in different regions, results may be significantly different. A comparative analysis on global and regional land cover classifications is discussed in the following section.

At present, there are mainly three satellite sensors for land cover detection and mapping at the global level: National Oceanic and Atmospheric Administration - Advanced Very High Resolution Radiometer (NOAA AVHRR), Systeme Pour l'Observation de la Terre (SPOT) VEGETATION and Moderate Resolution Imaging Spectroradiometer (MODIS). Dataset from these sensors are available on daily basis. They have been widely used for global land cover detection and in relevant fields as a baseline for global environment change, climate and hydrological models and so on to predict future scenario. NOAA AVHRR data, among these satellite data, is the most widely used data due to its longest history record and data consistency. Along with data availability at the global level from various satellites, many legends and classification methods for global land cover have been developed and are applied to monitoring land cover and providing parameters for climate models. Comparative analysis between different land cover products at global level is a very important step for improving current products and to use appropriate data for our specific study area. The four freely downloadable global satellite-based 1km land cover products that are widely used by the international science community are:

- International Geosphere Biosphere Program Data and Information System Land Cover (IGBP-DISCover)
- University of Maryland (UMd) Global Land Cover
- Global Land Cover 2000 (GLC2000)
- MODerate resolution Imaging Spectroradiometer (MODIS)

International Geosphere Biosphere Program Data and Information System Land Cover (IGBP-DISCover)

The IGBP land cover classification includes 11 classes of natural vegetation covers distinguished by life form, three classes of urban and cropland mosaic lands and three classes of non-vegetated lands for a total of 17 classes (Strahler *et* al. 1999). The legend is aimed to be exhaustive so that every part of the earth's surface was assigned to a class; exclusive so that classes would not overlap; and structured so that classes are equally interpretable. This was developed through a continent by continent unsupervised classification of 1 km NOAA AVHRR normalized difference vegetation index (NDVI) composites from 1991–1993 (Loveland *et* al. 2000). Problem areas include wetlands that were underrepresented in the database due to difficulty in separating trees, shrubs and water along with the small size of many wetland areas (Loveland *et* al. 2000). The overall area-weighted accuracy of the dataset was determined to be 66.9% (Scepan 1999).

University of Maryland (UMd) Global Land Cover

The IGBP dataset creation was followed shortly by the UMd global land cover dataset. The UMd approach involves a supervised method where the entire globe was classified using a classification tree algorithm. The tree predicts class memberships from metrics derived from the same NOAA AVHRR data employed by Loveland *et* al. (2000)

except that all five spectral bands as well as NDVI values were used (Hansen and Reed 2000). The UMd utilized a simplified IGBP classification with 14 classes. The classes of permanent wetlands, cropland/natural vegetation mosaic and ice and snow were not used. Problem areas included those of low biomass agriculture, high-latitude broadleaf forest and temperate pastures within areas of agriculture. The agreements for all classes varied from an average of 65% when viewing all pixels to an average of 82% when viewing only those 1 km pixels consisting of more than 90% of one class within the high-resolution datasets (Hansen and Reed 2000).

Global Land Cover 2000 (GLC2000)

In contrast to former global mapping initiatives the GLC2000 project is a bottom-up approach to global mapping (Fritz et al. 2003). Regional experts were identified from around the globe to classify 19 regional windows (each with a unique regional legend), which were then combined into a global product. The dataset was based on daily data from the SPOT-4 VEGETATION though mapping of some regions involved other Earth observing sensors to resolve specific issues. The GLC2000 utilizes a global classification based on the Land Cover Classification System (LCCS) legend of 23 classes. The product has been visually validated by a number of experts and the overall response has been very positive. A comparison of overlapping regions between Eurasia, Asia and Europe recorded a maximum of 64.26% agreement (Fritz et al. 2003). The accuracy assessment relied on quality control based on a comparison with ancillary data and a quantitative accuracy assessment based on a stratified random sampling of reference data (LandSat ETM+ imagery). First results of the accuracy assessment indicate similar accuracies as the IGBP dataset (GOFC-GOLD 2004).

MODerate Resolution Imaging Spectroradiometer (MODIS)

In the MODIS global land cover dataset, land cover classes are produced by processing the 32-day database using decision tree and artificial neural network classification algorithms based on training data (Strahler et al. 1999). The MODIS dataset was classified according to the IGBP legend with 20 classes in total. The estimated accuracy of the IGBP layer of the Consistent-Year Land Cover product (2003) is 75–80% globally; 70–85% by continental regions; and from 60 to 90% for individual classes.

Land cover mapping for South Central Asia

At the regional level, a land use/land cover map for South Central Asia region was prepared by Indian Institute of Remote Sensing (IIRS) as a part of Global Land Cover Map produced by Joint Research Centre (JRC), Italy with an objective to provide a uniform and consistent data set comparable across the regions and countries for the reference year 2000. SPOT-4 VEGETATION and other ancillary information were used for the study. The classification scheme is based on LCCS, while incorporating the Champion and Seth scheme for defining the classes which are relevant to Indian sub-continent.

Table 1.1: Land cover data and legends at global level

	IGBP	UMD	GLC2000	MODIS
Sensor	NOVAA AVHRR	NOVAA AVHRR	SPOT-4 VEGETATION	Terra MODIS
Time of data Collection	April 1992– March 1993	April 1992– March 1993	November 1999 –December 2000	October 2000– October 2001
Input data	12 Monthly NDVI Composites	41 Metrics derived from NDVI and bands 1–5	Daily mosaics of 4 spectral channels and NDVI	12, 32-day composites of 8 input parameters
Classification Technique	Unsupervised clustering	Supervised classification decision tree	Generally unsupervised classification	Supervised decision-tree classifier, neural networks
Classification Scheme	IGBP (17 classes)	Simplified IGBP (14 classes)	FAO LCCS (23 classes)	IGBP (20 classes)
Validation	High resolution satellite images	Used other digital datasets	Statistical sampling	Confusion matrices confidence values
Supplemental data	DEM, ecoregions, vegetation, land cover	Coarse/fine resolution satellite data	Data from other sensors	Fine resolution imagery with ancillary data

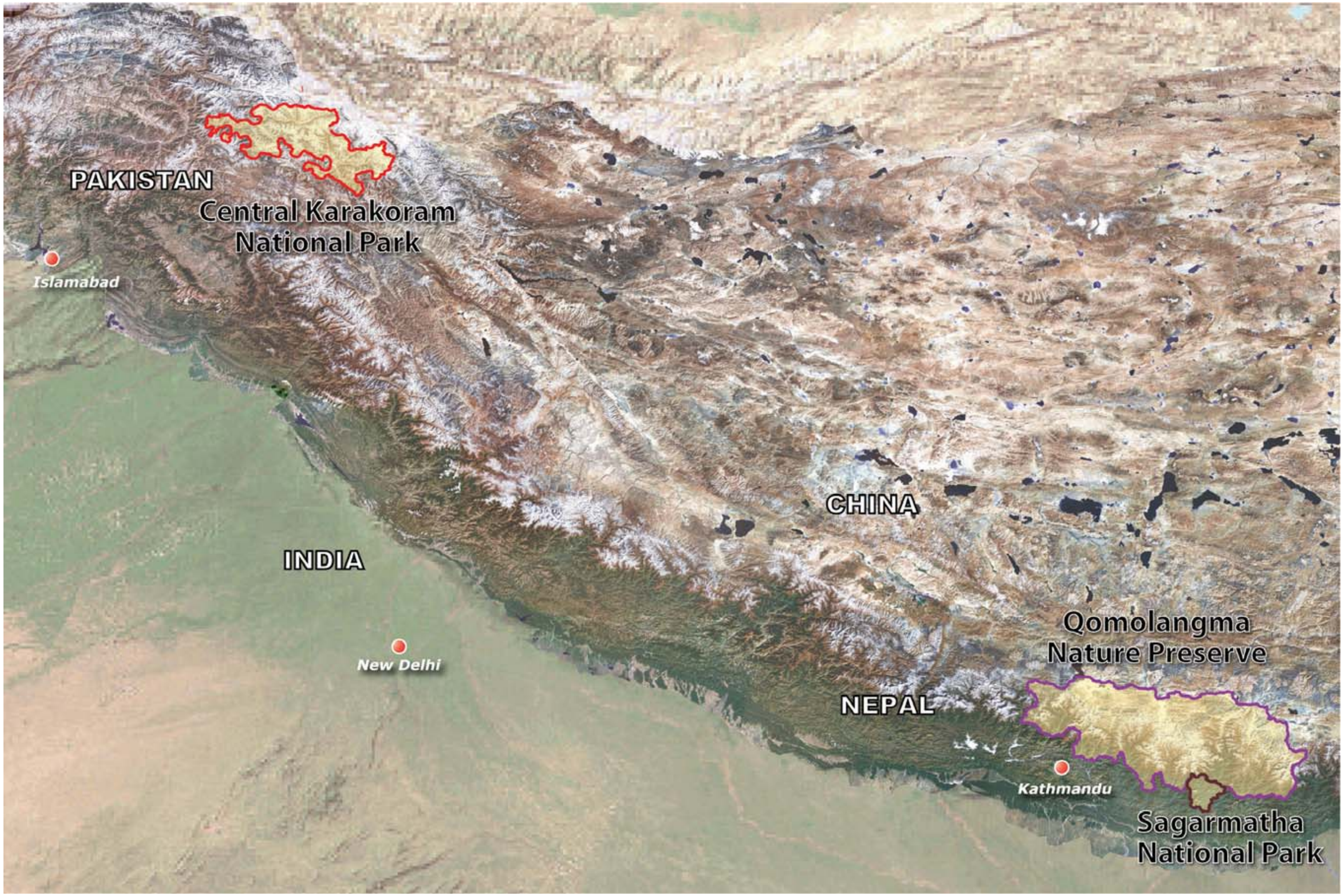
Giri et al. (2005) compared GLC2000 and MODIS global land cover data to evaluate the similarities and differences in methodologies and results, and to identify areas of spatial agreement and disagreement. McCallum et al. (2006) compared the four global land cover dataset, namely IGBP, MODIS, UMd and GLC2000. These four global land cover data sets were prepared using different data sources, classification systems, and methodologies (see Table 1.1), but using the same spatial resolution (i.e., 1 km) satellite data. The analysis shows that while these datasets in many cases are in agreement at a global level in terms of total area and general spatial pattern, there is limited agreement on the spatial distribution of the individual land classes. If global datasets are used at a continental or regional level, agreement in many cases decreases significantly.

Land cover classification criteria adopted by different initiatives in the HKKH region

There are quite a few enumerations on land use and land cover types from the HKKH region (Champion 1936, Champion et al. 1965, Champion and Seth 1968, Stainton 1972, Dobremez 1976, , Olson and Dinerstein 2002, NARMSAP 2002 and also see Table 1.2). These enumerations have different legends mainly manifested by the vegetation and land cover types and the objective of the respective work. When analyzed, it revealed that most of these land cover classifications were based on eight broad categories (Table 1.2).

Table 1.2: Major types of land classification based on different classification criteria available from the HKKH region

Categories	Classifications	Examples	References
1	Land use classes	Forested land, Cultivated lands, Built up areas, Water bodies, Barren land, Snow cover	Olson & Dinerstein 2002, NARMSAP 2002
2	Life form	Forests, Shrubs, Scrubs, Grassland, Savannas, Meadow	Schweinfurth 1957, Dobremez 1976, Olson & Dinerstein 2002, NARMSAP 2002
3	Canopy coverage	Open forests, Closed forests, Abandoned jhum, Vegetated,Non-vegetated, Tree cover, Shrub cover, Herbaceous cover	Champion & Seth 1968, Roy et al. 2004, Di Gregorio 2005
4	Climatic factors e.g., Precipitation	Moist, Wet, Dry, Humid, Swamp	Schimper 1903, Shangbag 1958, Gaussen 1959, Champion & Seth 1968, Dobremez 1976, Roy et al. 2004
5	Bioclimatic zones or ecoregions	Subtropical, Tropical, Sub temperate, Temperate, Sub alpine, Alpine, Montane	Schweinfurth 1957, Champion & Seth 1968, Dobremez 1976; Olson et al. 2001, Wikramanayake et al. 2001, Olson & Dinerstein 2002, NARMSAP 2002
6	Species types	Needle leaf, Thorn, Pines, Conifers, Board leaf Mixed, Evergreen Deciduous	Kihara 1956, Schweinfurth 1957, Hara1966, Champion & Seth 1968, Wikramanayake et al. 2001, Olson & Dinerstein 2002
7	Species dominance	Oak, Oak-rhododendron, Pine-birch, Pine-spruce-fir etc.	Schweinfurth 1957, Hara 1966, Champion & Seth 1968, Dobremez 1976, NARMSAP 2002
8	Climatic and vegetation division	East, Central, West, Trans-Himalaya	Champion & Seth 1968, Dobremez 1976, NARMSAP 2002


PAKISTAN
Central Karakoram
National Park
Islamabad
CHINA
INDIA
New Delhi
Qomolangma
Nature Preserve
NEPAL
Kathmandu
Sagarmatha
National Park

2

Methodological Framework

Multi-scale approach in land cover mapping

Land cover maps provide knowledge about landscape patterns and their changes which are useful when assessing human induced drivers and their impacts to the ecosystem. The processes of change may have different impacts at different scales.

The three protected areas of project intervention vary greatly in spatial extent. The project has adopted a multi-scale approach in land cover mapping that will be useful in understanding the linkages at different scales. Therefore it was important to have a land cover mapping system which allowed aggregation at different level of details. Efforts have been made to develop a detailed land cover map of SNPBZ that is useful when managing and making decisions at the local level. Land covers of the same area with higher level of aggregation are generated to study the changes over time. Because the size of CKNP and QNNP are much bigger than compared to SNPBZ, land cover mapping of these areas are planned at the regional level. The project worked on developing methodologies that are compatible at local, national and regional scales.

Approaches for harmonization of land cover data

Selection of Land Cover Classification System (LCCS)

To commensurate the differences in land cover mapping efforts around the globe, a number of organizations and institutions are working on generalizing the classification systems and the legends for global consistency such as the Terrestrial Ecoregions of the World Project (Olson and Dinerstein 2002), GLC2000 (Fritz et al. 2003), Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD 2004), etc. However, very little efforts were made to compare and bring consistency in the global legend usage (Olson and Dinerstein 2002; Giri et al. 2005) and there was a demand for a consistent land use legends for the HKKH region (Gautam and Watanabe 2004). The initiatives taken by Food and Agriculture Organization of the United Nations (FAO) to bring the consistency in global land cover legends paved the way for more opportunities for harmonized land cover classification (Roy et al., 2004). The LCCS has been designed by FAO and United Nations Environment Programme (UNEP) in order to cope with the growing requirement of accessing the reliable and standardized information on land cover and land cover change analysis. The LCCS standard is a comprehensive and standardized a priori classification system designed to meet specific user requirements and created for mapping exercises independent of mapping scale, land cover type, data acquisition method, or geographical location. The LCCS was developed for the harmonization of geographic data as a result of the intensified use of Geographic Information Systems (GIS). It is currently in the approval process to be considered as an International Organization for Standardization (ISO) standard (Di Gregorio 2005).

The classification uses a set of independent diagnostic criteria that allow correlation with existing classifications and legends, which could serve as an internationally agreed reference base for land cover. This methodology is applicable at any scale and is comprehensive in the sense that any land cover identified anywhere in the world can be readily accommodated. The rearrangement of the land cover classes, based on regrouping of the used classifiers, facilitates the extensive use of the outputs by a wide variety of end-users. The LCCS has been designed with two main phases: an initial dichotomous phase, in which 8 major land cover types are defined, followed by a subsequent modular hierarchical phase, in which land cover classes are created by the combination of sets of predefined classifiers tailored to each major land cover type in order to use the most appropriate classifiers and to reduce the likelihood of impractical combinations of classifiers. A software program has been developed to assist in land cover interpretation, thus standardizing this process and contributing to its consistency. Despite the huge number of classes that can be generated, the user deals with only one classifier at a time and a land cover class is built up by a stepwise selection in which a number of classifiers are aggregated to derive the class.

An appropriate classification methodology selected for the project is very crucial because the three protected areas are diverse in their biophysical characteristics as a result of different land formation, climate conditions and other environmental factors. In addition, the three protected areas belong to three different countries with varying socioeconomic development levels, natural resources and management systems. In this context, the LCCS was considered for use in the project's land cover mapping activities.

Workshops on application of FAO/UNEP LCCS

A uniform land cover legend and classification system was essential for the project activities and the FAO/UNEP LCCS was chosen as the most appropriate approach. The project developed linkages with FAO/GLCN (Global Land Cover Network) and organized workshops in Nepal and Pakistan, focusing specifically on the needs of harmonizing within the project framework.

Workshop on application of FAO/UNEP LCCS for the study of land cover dynamics in SNPBZ, Kathmandu, 11-13 April, 2007.

To bring together the professionals working on ecosystem and land cover studies and provide them with the knowledge of LCCS methodology to facilitate development of a standardized land cover legend that will contribute to the harmonization at the sub regional and regional levels, a 3-day training workshop on "Application of FAO/UNEP Land Cover Classification System (LCCS) for the study of land cover dynamics in SNPBZ" was held from 11-13 April 2007 by ICIMOD. The workshop was facilitated by Dr. Antonio Di Gregorio, LCCS Coordinator from FAO/GLCN and was attended by 22 participants from project partners and stakeholders.

The workshop introduced the participants to the LCCS concepts and methodology for developing standardized land cover legends using LCCS software. Additionally the participants worked on developing a preliminary legend to be used for the development of the land cover map of SNPBZ.

Workshop on application of FAO/UNEP LCCS for the study of land cover dynamics in CKNP, Gilgit, 31October - 1 November, 2007.

A similar workshop was organized in Gilgit from 31 October to 1 November to introduce the stakeholder in CKNP to the LCCS concepts and methodology for developing standardized land cover legends using LCCS software. The workshop was organized at Karakoram International University premises and was attended by 27 professionals from different government, non-government and academic institutions in Pakistan. Participants shared their experiences on land cover mapping activities in Pakistan and came up with recommendations for the different classes that are relevant to CKNP. Based on the recommendations, a draft legend for CKNP was developed which was further refined after the field work.

Defining a classification methodology

State-of-the-art technologies like remote sensing, geographical information system, global positioning system and digital image processing have revolutionized the process of information gathering, processing and utilization for effective natural resource management. Satellite remote sensing is widely accepted as a technique for land cover mapping. It is widely used for the study of land cover dynamics as remote sensing can deliver data in a transparent and repeatable fashion without bias. There has been an increase in access to satellite-based land cover descriptions of the globe over the last decade with more products emerging in the market.

Recently, object-based image analysis is a promising methodology in automatic information extraction and case studies have shown that this methodology gives significantly better classification results (Harken and Sugumaran 2005, Benz et al. 2004, Hofmann 2001, Zhou et al. 2008, Jiang et al. 2008). Unlike the conventional pixel-based methods which only use pixel values, the object-based techniques can not only use the spectral feature but also texture information, neighborhood information, context information, and other related ancillary data to gain higher accuracy of land cover mapping (Blaschke et al. 2000, Caprioli and Tarantino 2001, Benz et al. 2004).

The project adopted object-based approach for land cover classification. The process is given in Figure 2.1. After rectification of the satellite image, different parameters such as NDVI, normalized difference snow and ice index (NDSII) and normalized difference water index (NDWI) are generated. These parameters help in differentiating vegetation types, soils, river, lake, as well as snow and ice.

Calculation of key parameters

Normalized Difference Vegetation Index (NDVI)

NDVI is a simple numerical indicator that is used most widely to simply and quickly identify vegetated areas in multispectral remote sensing data. It is based on the ratio between the maximum absorption of radiation in the red (Red) spectral band versus the maximum reflection of radiation in the near infrared (NIR) spectral band. Lacking the plants' absorption/ reflectance mechanisms, soil spectra typically do not show such a dramatic spectral difference (Volcani et al. 2005). This index was chosen because of its frequent use in vegetation studies and straightforward interpretation. This is the most commonly used vegetation index as it retains the ability to minimize topographic effects while producing a linear measurement scale. The measurement scale has a property ranging from -1 to 1. Thus, negative values represent non-vegetated areas (e.g. snow and water body) due to the higher reflectance in visible band and lower reflectance value in NIR band while positive values typically reflect vegetated areas with the characteristic of bigger value and vegetation state (e.g., biomass and vegetation cover percentage). The NDVI value of bare rock and bare soil is around 0 due to the similar spectral reflectance in the related band.

The following equation is used to calculate NDVI:
$NDVI = (NIR - Red) / (NIR + Red)$

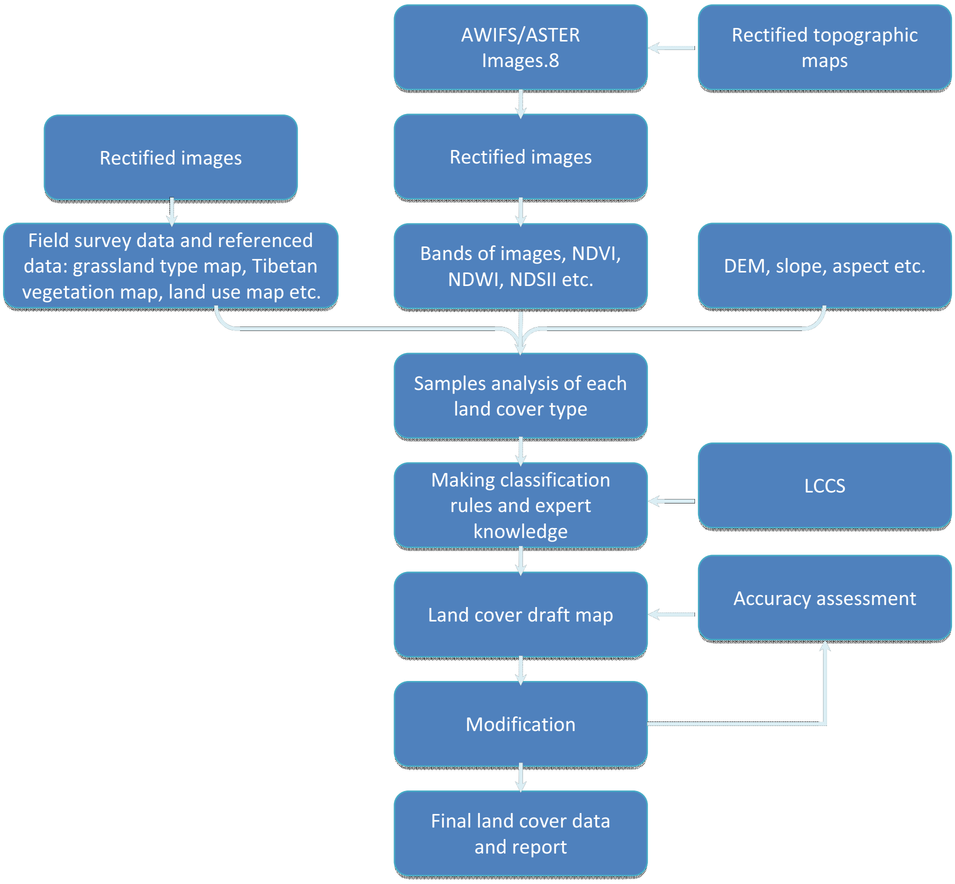


Figure 2.1: Methodology for land cover classification

Normalized Difference Snow/Ice Index (NDSII)

A key component of the snow mapping algorithm is the NDSII that was derived first to delineate snow covered areas. Snow and ice have very high reflectance values in visible spectral bands (blue, green and red), but very low reflectance in short wavelength infrared (SWIR) band. The NDSII employs visible and SWIR band data to identify snow cover and discriminate snow from other types. The spectral reflectance values of band3 (Red) and band5 (mid-infrared) for Advanced Wide Field Sensor (AWiFS) data, and band2 (Red) and band4 (SWIR) of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) were used to calculate the NDSII. The value is then normalized to the range -1<=NDSII<=1 to partially account for differences in illumination and surface slope. All the snow will carry positive value (Hall et al., 1998, Hulka, 2008). The following equations are used:

$NDSII_{AWIFS}$ = (Red – MIR)/ (Red + MIR)
$NDSII_{ASTER}$ = (Red – SWIR)/ (Red + SWIR)

Normalized Difference Water Index (NDWI)

NDWI is used widely and simply to identify the water body and moisture condition. Reflectance ratio of water body in NIR band is much lower than that in visible band. The NDWI makes use of reflected NIR radiation and visible green (Green) light to enhance the presence of such features while eliminating the presence of soil and terrestrial vegetation features. It has been suggested that the NDWI may also provide researchers with turbidity estimations of water bodies (McFeeters 1996). The following equation is used to calculate NDWI:

NDWI= (Green - NIR)/ (Green + NIR)

These different layers of NDVI, NDSII, NDWI, digital elevation model (DEM) and its derived information such as slope and aspect are used in combination with the rectified image for segmentation.

Segmentation

Segmentation is a crucial step in an object-based image analysis in which meaningful image objects are created (Definiens 2006). It is the subdivision of an image into separated regions represented by image objects which contain information about their spectral characteristic, shape, position and texture as well as information about their neighborhood. Different segmentation algorithms are used to subdivide the entire image represented by the pixel level domain or specific image objects from other domains into smaller image objects. A convenient approach for segmentation is to run different segmentations with different parameters until the result is satisfactory. Throughout the segmentation procedure, the whole image is segmented and image objects are generated based upon several adjustable criteria of homogeneity in color and shape. It is important to experiment until one obtains the parameters that best fit the image by changing the respective weights of color and shape because they have an influence on the classification result. Once suitable segmentation parameters have been found, they are tested on the whole data set.

Classification

After a satisfactory segmentation is achieved, the next step is classification, which is a procedure for associating image objects with an appropriate class. A class describes the semantic meaning of image objects in the cognition network. The classes form a structured sub-network of the cognition network called the class hierarchy. The image objects can be classified according to particular criteria. Different classes are related and arranged in semantic groups, which represent knowledge. This structure of knowledge representation allows automated image analysis. The classes defined in LCCS are inserted before starting the classification. Class descriptions are created via a fuzzy logic-based system. Image objects are linked to class objects by classification link objects. Each classification link stores the membership value of the image object to the linked class.

An image object may have an arbitrary number of classification links. The class with the highest membership value for the image object is called the current class of the image object. The classification algorithm evaluates the membership value of an image object to a list of selected classes. The classification result of the image object is updated according to the class evaluation result. Another algorithm for classification is the Nearest Neighbour classifier which classifies the image objects based on given sample image objects within a defined feature space. This is similar to supervised classification in pixel-based classification. After a representative set of sample objects has been declared for each class, each image object is assigned to the class of the nearest sample object in the feature space.

Post classification processing

After the classification, the result is checked for accuracy and the steps are repeated if necessary. The data is exported into shape files and the areas which are smaller than the defined minimum mapping units are eliminated. The standard codes and LCCS labels are imported and the topology updated to produce the final land cover map.

The land cover maps for all the three protected areas are generated using these similar methodologies. However, different image data are used according to their suitability and availability in the context of these areas. The land cover mapping activities in SNPBZ, CKNP and QNNP and the results are presented in the following sections.


Birendra Bajracharya

3

Land Cover Mapping of Sagarmatha National Park and Buffer Zone (SNPBZ)

Study area

SNPBZ is located about 140 km east of Kathmandu in the northern regions of Solukhumbu District at 27°45'-28°07'N and 86°28'-87°07'E. It is bordered to the east by Makalu-Barun National Park, Rolwaling Valley of Dolakha District to the west, and QNNP in TAR of China to the north.

The park encompasses the upper catchment of the Dudh Kosi River system, which forms a distinct geographical unit enclosed on all sides by high mountain ranges. The northern boundary is defined by the main divide of the Great Himalayan Range, which follows the international border with the TAR of China. The national park is located amidst the world's tallest peaks, the Mount Everest (8,850 m), Lhotse (8,601m) and Cho Oyu (8,153m). Other well known peaks such as Thamserku, Pumori, Ama Dablam, Kongde and Kangtega are also located nearby. The map of SNPBZ is presented in Figure 3.1.

Climate

The climatic conditions of SNPBZ are determined by the monsoon. Seventy to eighty percent of annual precipitation occurs in the summer (June-September) with the remainder of the year being relatively dry and cool. Relative humidity remains at 100% even in the upper valleys during monsoon, and humidity rapidly decreases

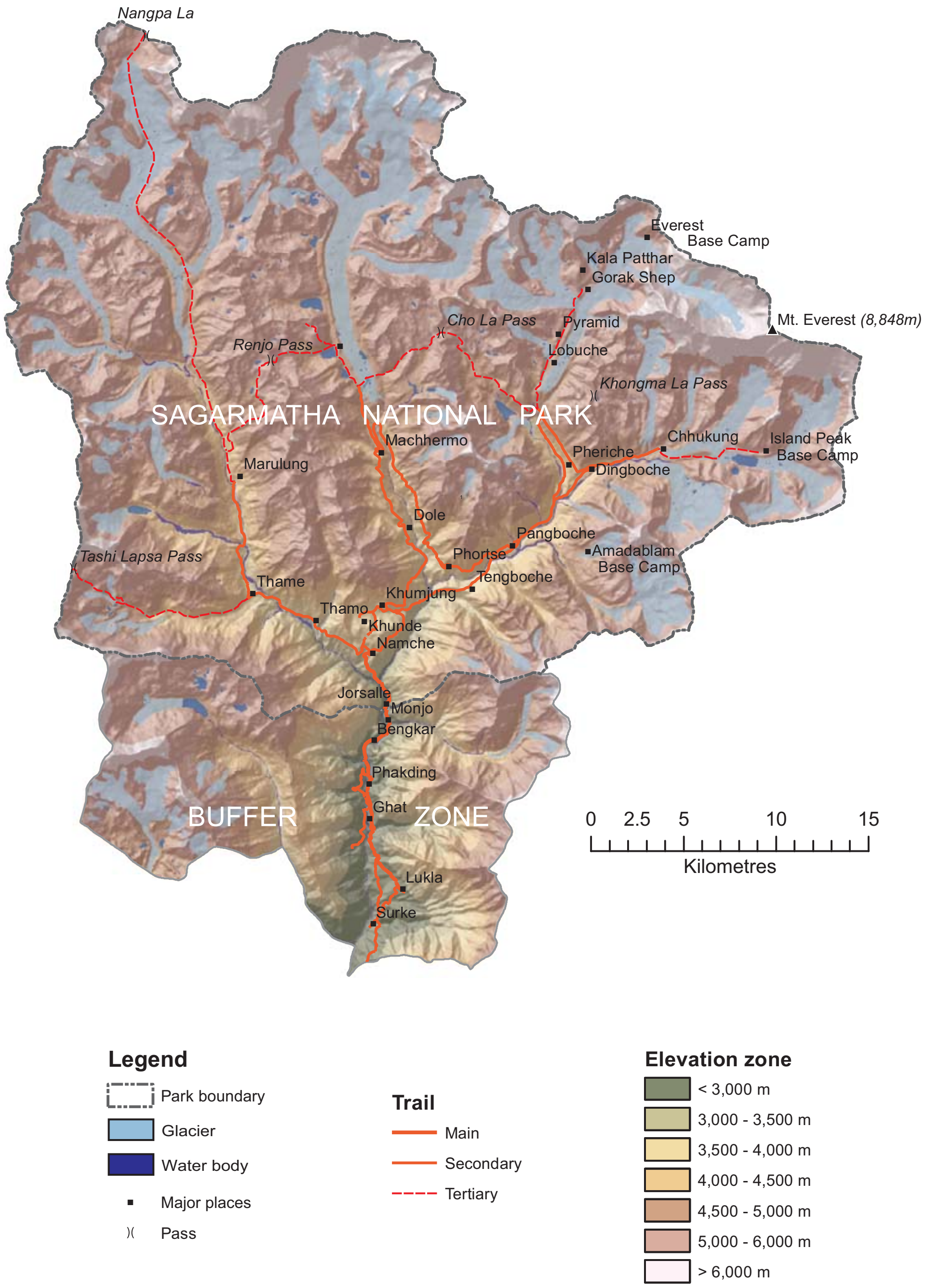


Figure 3.1: Map of SNPBZ

after monsoon. Climate of SNPBZ therefore can be described as generally moist and cool in the summer and cold and dry in the winter. There are marked variations in temperature and precipitation influenced by altitude and seasons. Temperature recorded at Thamo Village (3400 m) showed maximum mid-summer (June and July) temperature that remained above 18ºC. The minimum temperature fell to -6ºC in January. Light snow begins to fall in the autumn but the accumulation of winter snow rarely exceeds 1 m in the park and less so in the lower Buffer Zone area. Gale force winds are common in the higher elevation areas during the winter months. The upper area is slightly drier than the Buffer Zone area because the park area is partially screened from the full force of monsoon by the Kongde and Thamserku ranges.

Ecology

Five bioclimatic zones are found within the limited area of SNPBZ. Nearly 58% of the total area of the SNPBZ falls within the Nival zone located above 5000 m elevation. This is the zone of bare soil, rocks, snow and ice and has very limited vegetation cover. Many active glaciers are located in this zone. The Nival zone is one of the most important reservoirs of water stored in the form of ice and snow. Vegetation such as *Rhododendron nivale*, *Androsace, Primula*, blue poppy, *Rodiola, Poa* and *Festucca* grasses may be found. The area between 4000 to 5000 m is the Alpine zone which occupies about 31% of the total area of the SNPBZ. Much of the vegetation found in this zone are stunted shrubs (*R. antohopogon, R. setosum, Juniperus wallichiana, Salix calyculata* and *Casshiope fastigiata*) tolerant of cold conditions. The low winter temperature limits growth of taller vegetation. Despite the lack of vegetation and cold winter conditions, the Alpine zone is an important area for grazing high altitude yak and *naks* and more recently for tourism and mountaineering. The Sub-Alpine zone covers a narrow band between 3000 to 4000 m elevation. Only 13% of the area falls within this zone. The Sub-Alpine zone is generally forested and the dominant species are *Abies, Pinus, Junipeurs, Betula, R .campanulatum* and *R. campylocarpum*. The upper limits of this forest extend to 3900 m on cool slopes whereas on warmer slopes this line is blurred by fire, grazing and harvesting influences. Cool-Temperate zone between 2000 and 3000 m is the area for growing productive forest. Only 3% of the SNPBZ falls within the Cool-Temperate zone. The diversity of flora and fauna is naturally higher in this zone because of warmer and moister conditions. Majority of the Cool-Temperate zone falls outside the park in the SNPBZ. The major temperate tree species are *Tsuga, Pinus, Qeuercus, Rhododendrons* and laurel species. Much of the leveled or moderately sloping areas are converted to agriculture and pastures under private and community ownership. A very small area falls under the Warm-Temperate zone which is restricted to lower gorge of the Dudhkosi below Chaurikharka. The species of vegetation and wildlife found in this area are not very different from the lower belt of the Cool-Temperate zone. The main difference is that snow rarely falls in this zone.

Geology and soils

The SNPBZ is characterized by high, geologically young mountains and glaciers. The outstanding features of the park are its majestic peaks which are higher than 8,000 m. These magnificent mountain peaks are uplifted by collision of the Eurasian and Indian continental plates approximately 120 million years ago. Evidence indicates that the uplift is still continuing at a slower rate, but natural erosion processes counteract this to an unknown degree. The young and steep landscape is subject to erosion and other changes, both gradual and sudden. The upper valleys of the park are dominated by wider U-shaped valleys of glacial origin and the lower buffer zone area is marked mostly by river carved V-shaped valleys. Soils of SNPBZ are mostly of glacial, fluvio-glacial and fluvial origin. Their development is highly influenced by climate which changes with elevation.

Population

About 90% of the population of SNPBZ are Sherpas who are believed to have migrated to the area in the late 1400s to early 1700s from eastern Tibet. The census in 2001 (CBS 2002) showed a population of 5,869 permanent residents settled in more than 100 settlements of varying sizes. More than 90% of the people residing in the SNPBZ are Buddhists and the remaining 10% are Hindus and Kirat. The majority of the Buddhists are local Sherpa people who have been residing in the area for centuries. There are many ancient monasteries in the major settlements of the park. Major cultural festivals and ceremonies of the Sherpas such as Losar (New Year), Dhumji, Mani Rimdu and Nyingne are observed showing the rich culture and tradition of the local people.

The traditional economic activities of the people were subsistence agriculture and transhumance herding supplemented by barter trade across the Himalayas with Tibet. The economy of the area began to change rapidly after Khumbu began to attract an increasing number of mountaineering and trekking groups following the opening of Nepal to foreign visitors in 1950. Tourism-related activities such as climbing, portering, guiding and lodge management have become dominant economic activities. Absorption of significant portion of labor force by tourism sector has had a major impact on the viability of farming and herding systems. About 22% of the households in SNPBZ are dependent entirely on agriculture and about 37% are said to be partially involved.

Previous land cover mapping initiatives

The first forest resources measurement of Nepal was carried out between 1963 and 1965 by USAID (United States Agency for International Development) and the Government of Nepal. It included interpretation of 1:12,000 aerial photographs acquired in 1962 and 1:60,000 aerial photographs acquired from 1953 to 1958. The mostly barren high Himalayan area was not covered at all with some gaps in hill region (Wallace 1988). Another extensive mapping was carried out by the Government of Nepal and Canada under the land resources mapping project (LRMP 1986) in the early 1980s. Through this project the land use classification system for Nepal was developed and a nationwide land utilization mapping at a scale of 1:50,000 was completed. The classification system was designed so that as much data as possible could be extracted by the various users. The most recent land cover mapping was carried out by the Department of Forest Resources Survey, Government of Nepal with the cooperation of Japan Forest Technical Association (DFRS 1999, JAFTA 2001). Altogether 12 land use and land cover classes including six forest classes were separated using LandSat TM and IRS 1D satellite data from 1998 and 1999.

Development of legend

The participants of the workshop on LCCS methodology held in Kathmandu worked in groups to come up with preliminary legends for SNPBZ in view of different types of vegetation present there. These legends were synthesized to come up with a draft legend based on LCCS classification and circulated among the partners. A field mission to SNPBZ was carried out to collect samples for image interpretation and classification as well as to refine the legend. After several iterations, the classes were identified as shown in Table 3.1.

Table 3.1: LCCS legend for SNPBZ

LCCCode	LCCLevel	LCCOwnLabel	LCCLabel
6002-1	A3-A7	Bare Rock	Bare Rock(s)
6002-2	A3-A8	Gravels, Stones and Boulders	Gravels, Stones And/Or Boulders
6005	A5	Bare Soil	Bare Soil And/Or Other Unconsolidated Material(s)
5001	A1	Built Up Area	Built Up Area(s)
8001-1	A1-A4	River	Natural Waterbodies (Flowing)
8001-5	A1-A5	Glacier Lake	Natural Waterbodies (Standing)
8005	A2	Snow	Snow
8008-9	A3-A6	Glacier	Ice (Moving)
7001-5	A1-A5	Artificial Waterbodies	Artificial Waterbodies (Standing)
11498	A3XXXXXXD1	Cultivated area	Rainfed Herbaceous Crop(s)
20611-15047	A3A10B2XX D2E1F2F5F7 G2-E3F9	Multilayer Mixed Forest	Multi-Layered Mixed Trees

20091	A3A10B2XXD2	Needleleaved Closed Forest	Needleleaved Closed Trees
20133	A3A11B2XXD2	Needleleaved Open Forest	Needleleaved Woodland
20088	A3A10B2XXD1	Broadleaved Closed Forest	Broadleaved Closed Trees
20130	A3A11B2XXD1	Broadleaved Open Forest	Broadleaved Woodland
20151	A4A10B3XXD1	Broadleaved Closed Shrubland	Broadleaved Thicket
20172	A4A11B3XXD1	Broadleaved Open Shrubland	Broadleaved Shrubland
20155-15045	A4A10B3XX D2E1-E3	Mixed closed shrubland (Thicket)	Mixed Thicket
20176-15045	A4A11B3XX D2E1-E3	Mixed Open Shrubland	Mixed Shrubland
20154	A4A10B3XXD2	Needleleaved Closed Shrubland	Needleleaved Thicket
20175	A4A11B3XXD2	Needleleaved Open Shrubland	Needleleaved Shrubland
20018-12050	A4A10B3-B10	Dwarf closed shrubland	Closed Dwarf Shrubland (Thicket)
20022-12050	A4A11B3-B10	Dwarf open shrubland	Open Dwarf Shrubs (Shrubland)
21454-121340	A2A20B4-A21	Closed to Open Herbaceous vegetation	Herbaceous Closed to Open (100-40)% Vegetation

Reference data collection (field mission to SNPBZ)

Following the workshop, a field excursion to the SNPBZ was launched between 22 April and 12 May, 2007 with the following objectives:

- Develop a standard, easily replicable sampling methodology for the documentation of environmental, vegetative, and other land cover variables and attributes,
- Collect field data including the attributes required for the LCCS classification which will be used as signatures for image interpretation and classification,
- Collect a representative sample of ground cover data using 20 x 20 m quadrants and GPS-linked data points for the purpose of ground truthing the satellite images

The team spent a total of three weeks in the field covering detailed surveys of all four major watersheds of the SNPBZ: the Dudh Koshi (Lukla to Monjo), Bhote Koshi

(Thame Valley), Dudh Koshi (Gokyo Valley), and Imja Khola (Chhukhung and Khumbu Glacier Valleys). Land cover data were collected from a range of ground cover types that included:

a) Low altitude (<2700 m) *Quercus semicarpifolia* forests,
b) Low altitude (<2700 m) *Pinus wallichiana*; and *Tsuga dumosa*, *Pinus wallichiana*, and *Schima wallichi* forests,
c) Mid-altitude (3,000-3900 m), north-facing *Betula utilis/Rhododendron campanulatum- camplycarpum/Abies spectabilis/Juniperus recurva* forests,
d) Mid-altitude (3,000-3900 m), south-facing shrub-grasslands of *Cotoneaster microphylus/Rhododendron lepidotum/Berberis sp*., and
e) High altitude (>4,000 m) alpine ecosystems of shrub *Juniper indica/ Rhododendron lepidotum/Anaphalis sp./Graminae sp.*

Data were collected from fifty 20 x 20 m sampling plots and 110 GPS-linked descriptive data points, and more than 1,700 photographs from all locations were taken. Data sheets were used for recording the location's environmental attributes such as major landforms, slope classes, lithology, soils, and erosion phenomena as required by LCCS classification. Latitude, longitude, altitude, aspect, slope, soils, bedrock, and location were recorded for each site. Forest information included percent crown cover, tree species, height, dbh (diameter at breast height), number of seedlings, number of saplings, number of cut or damaged trees, percent ground cover, and dominant shrub and ground layer species. Shrubland/Alpine data collected included percent coverage of main plant species (e.g., shrub juniper, *Cotoneaster sp.*, dwarf rhododendron, herbaceous), bare ground, rock and detritus. Other environmental attributes, in addition to those listed above, included a descriptive paragraph of the location's general physiography, geomorphology, vegetation, and disturbance, both natural and human induced. Photographs were taken of each plot. Quadrate sites were subjectively selected on the basis of their ability to portray typical and representative land cover phenomena for the particular setting (e.g., birch/ rhododendron/ fir forest, shrub/ grassland, alpine shrub juniper/ dwarf rhododendron, oak/ hemlock forest, etc.).

It became clear that disturbance data were conspicuously absent from the Environmental Attributes data sheets, which were considered to be some of the most valuable information that a land manager needs for informed decisions in addition to the general description attributes of major landform (e.g., level land, sloping land, steep land, slope classes etc.). The following information was also collected as additional attributes.

Erosion and disturbance

A. No Visible Erosion

B. Visible Erosion
Water
Wind
Mass Wasting (overland flow, sediment splays)

C. Cattle Terracettes

Heavy	> 6/plot
Medium	3-6/plot
Low	< 3/plot

D. Cattle Disturbance

Heavy	> 50 percent of plot surfacially disturbed
Medium	25-50 percent of plot surfacially disturbed
Low	<25 percent of plot surfacially disturbed

E. Anthropogenic Disturbance
(note type: burning, root/stump digging, tree/shrub cutting)

Heavy	> 50 percent of plot surfacially disturbed
Medium	25-50 percent of plot surfacially disturbed
Low	<25 percent of plot surfacially disturbed

F. Natural Disturbance
(note type: needle ice, turf exfoliation, mass wasting)

Heavy	> 50 percent of plot surfacially disturbed
Medium	25-50 percent of plot surfacially disturbed
Low	<25 percent of plot surfacially disturbed

The locations of the sample plots and observation points are shown in Figure 3.2.

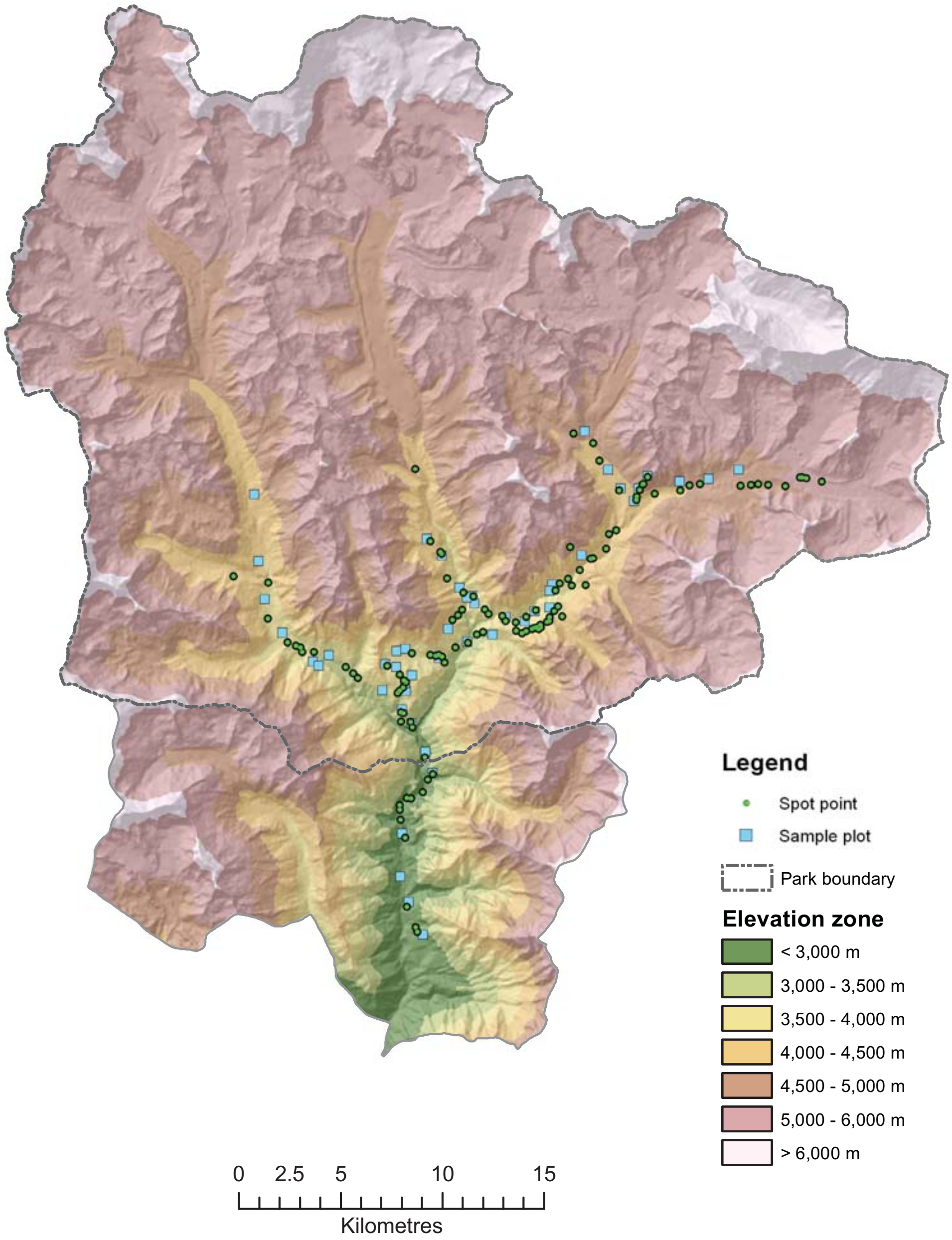


Figure 3.2: Location of sample plots and observation points

Field examples of land cover classes

Bare Rock

Bare Soil

Broadleaved Closed Forest

Broadleaved Closed Shrubland

Broadleaved Open Forest

Broadleaved Open Shrubland

Built Up Area

Closed to Open Herbaceous Vegetation


Cultivated Area


Dwarf Closed Shrubland

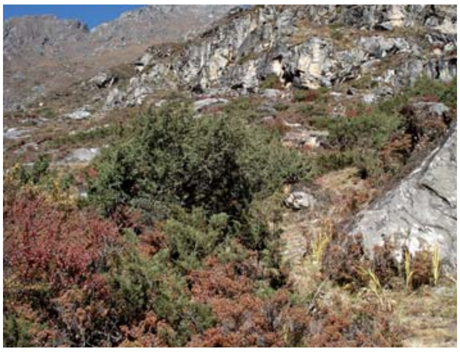

Dwarf Open Shrubland


Glacial Lake


Glacier


Gravels, Stones and Boulders


Mixed Closed Shrubland (Thicket)


Mixed Open Shrubland


Multilayer Mixed Forest


Needleleaved Closed Forest


Needleleaved Closed Shrubland


Needleleaved Open Forest


Needleleaved Open Shrubland


River


Snow

Figure 3.3: Examples of land cover classes from the field

Materials and methods

Satellite images

The satellite images used for the land cover mapping activities of SNPBZ are presented in Table 3.2.

Table 3.2: List of satellite images

Satellite	Sensor	Band		Resolution	Acquisition Date
IKONOS	IKONOS-2	Pan	0.45 - 0.90 microns	1 m	1 Jan, 2002
		Band 1	0.45 - 0.53 microns (blue)	4 m	
		Band 2	0.52 - 0.61 microns (green)	4 m	29 Nov, 2001
		Band 3	0.64 - 0.72 microns (red)	4 m	
		Band 4	0.77 - 0.88 microns (nir)	4 m	
LandSat	ETM+	Band 1	0.45 - 0.52μm (blue)	30 m	30 Oct, 2000
		Band 2	0.52 - 0.60μm (green)	30 m	
		Band 3	0.63 - 0.69μm (red)	30 m	
		Band 4	0.75 - 0.90μm (nir)	30 m	
		Band 5	1.55 - 1.75μm (infra-red)	30 m	
		Band 6	10.4 - 12.50μm (tir)	60 m	
		Band 7	2.08 - 2.35μm (nir)	30 m	
		Band 8	0.52 - 0.90μm (pan)	15 m	
LandSat	TM	Band 1	0.45 - 0.52μm (blue)	30 m	17 Nov, 1992
		Band 2	0.52 - 0.60μm (green)	30 m	
		Band 3	0.63 - 0.69μm (red)	30 m	
		Band 4	0.76 - 0.90μm (nir)	30 m	
		Band 5	1.55 - 1.75μm (infra-red)	30 m	
		Band 6	10.40 - 12.50μm (tir)	120 m	
		Band 7	2.08 - 2.35μm (nir)	30 m	
Terra	ASTER	Band 1	0.52-0.60 (Green)	15 m	1 Feb, 2006
		Band 2	0.63-0.69 (Red)	15 m	
		Band 3	0.76-0.86 (Near IR)	15 m	
		Band 4	1.60-1.70 (SWIR)	30 m	
		Band 5	2.145-2.185 (SWIR)	30 m	
		Band 6	2.185-2.225 (SWIR)	30 m	
		Band 7	2.235-2.285(SWIR)	30 m	
		Band 8	2.295-2.365 (SWIR)	30m	
		Band 9	2.36-2.43 (SWIR)	30 m	
		Band 10	8.125-8.475 (TIR)	90m	
		Band 11	8.475-8.825 (TIR)	90m	
		Band 12	8.925-9.275 (TIR)	90m	
		Band 13	10.25-10.95 (TIR)	90m	
		Band 14	10.95-11.65 (TIR)	90m	

The land cover map was generated from interpretation and classification of the IKONOS images. These high resolution images were very useful for interpretation of different land cover classes. Although in terms of the area, the IKONOS image covered about 53% of the total area of SNPBZ (figure 3.4), it covered all the area below 4500 m elevation and therefore included almost all the vegetation areas of the four valleys.

ASTER image of 2006 was used to generate the latest land cover map of the whole SNPBZ. The LandSat TM image of 1992 and LandSat ETM+ image of 2000 were used for generating the past land covers and for studying the changes.

Methodology

Minimum mapping units

The minimum mapping units were taken as 1 ha (~ 25x25 pixels) for IKONOS multispectral images. For the class "Natural Waterbodies (flowing)" or river and adjacent gravels, stones and boulders, it was taken as 0.75 ha to retain the patches of water in the river which were clearly identifiable in the IKONOS images. Similarly, a minimum mapping unit of 2.5 ha was chosen for LandSat TM, LandSat ETM+ and ASTER images because this size was easily identifiable in these images.

Calculation of key parameters

The parameters such as NDVI, NDSII and NDWI were generated for each image as described earlier using ERDAS Imagine®. These layers along with DEM were inserted in Definiens® software, which was used for the object-based image analysis.

Segmentation

In the present analysis, the multi-resolution algorithm was used for segmentation. It is a heuristic optimization procedure that locally minimizes the average heterogeneity of image objects for a given resolution. It can be applied on the pixel level or an image object level domain. After a number of trials, a scale parameter of 100 was adopted. The scale parameter determines the maximum allowed heterogeneity for the resulting image objects. Modifying the value in the scale parameter varies the size of image objects. Similarly, the values of color and shape parameters were taken as 0.85 and 0.15, respectively. These values define the percentage contributions of spectral and spatial homogeneity in defining the image objects. An example of segmentation of IKONOS image is presented in Figure 3.5.

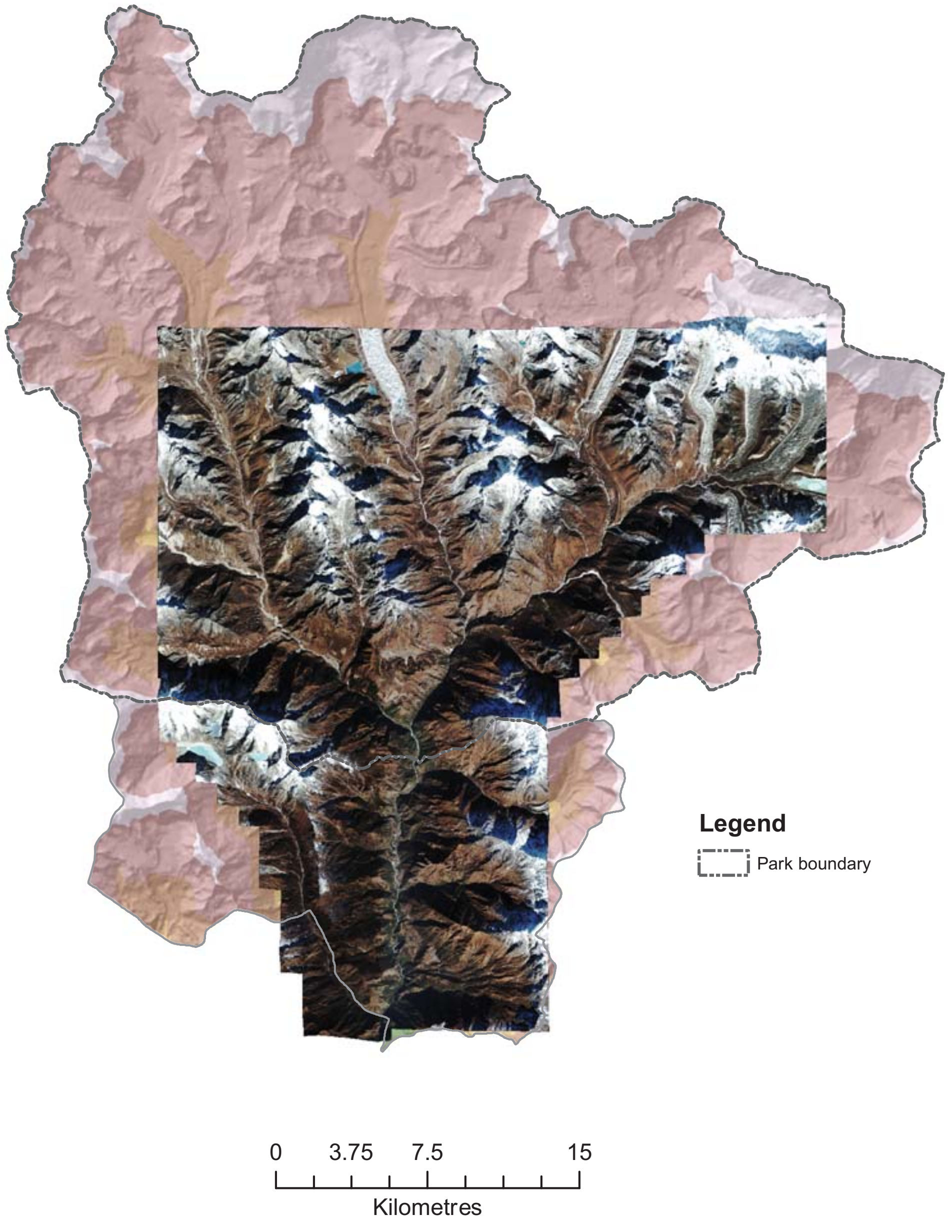


Figure 3.4: Area coverage of IKONOS images

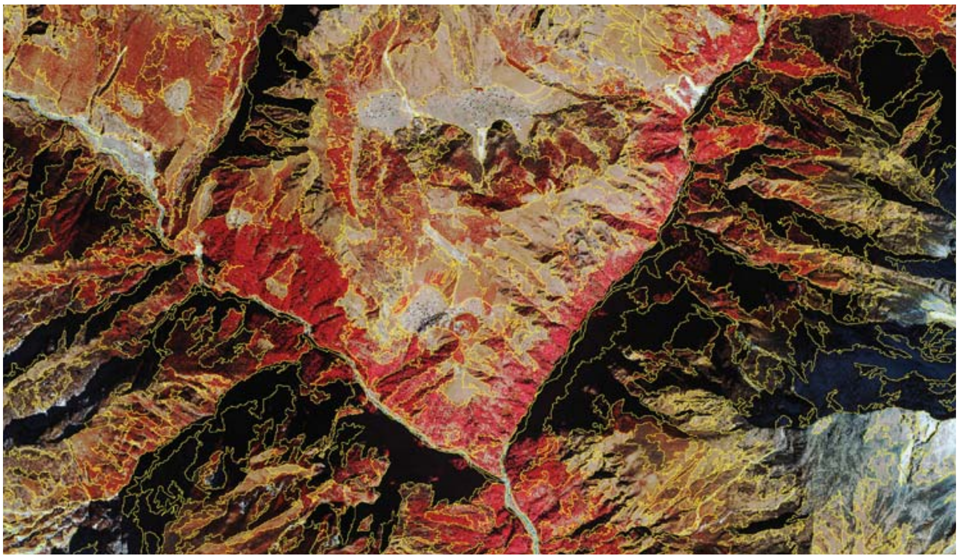


Figure 3.5. Segmentation of IKONOS image

Classification

The classes defined in LCCS were inserted in Definiens® before starting the classification. Class descriptions are created via a fuzzy logic-based system. Image objects are linked to class objects by classification link objects. Each classification link stores the membership value of the image object to the linked class. The standard nearest neighbor classifier was used in the present classification process. The classification was done separately for vegetated area and non-vegetated area using the NDVI mask.

Post classification processing

After the classification, the data is exported into shape files and the areas which are smaller than the defined minimum mapping units are eliminated. The standard codes and LCCS labels are imported and the topology updated to produce the final land cover map in ArcGIS®.

Results

Land cover from IKONOS

The final land cover data is derived from the IKONOS image as shown in Figure 3.6. The total area of the land cover data within the SNPBZ boundaries is 75,156 ha (see Table 3.3) which covers about 53% of the total area of SNPBZ. Out of this, 22%of the area is covered by bare rocks followed by 10% snow. Cultivated area makes only about one percent. Forests of different types cover 15%, shrubs cover 18% and dwarf shrubs cover 13% of this area. The areas above 6,000 m consist of bare rock, bare

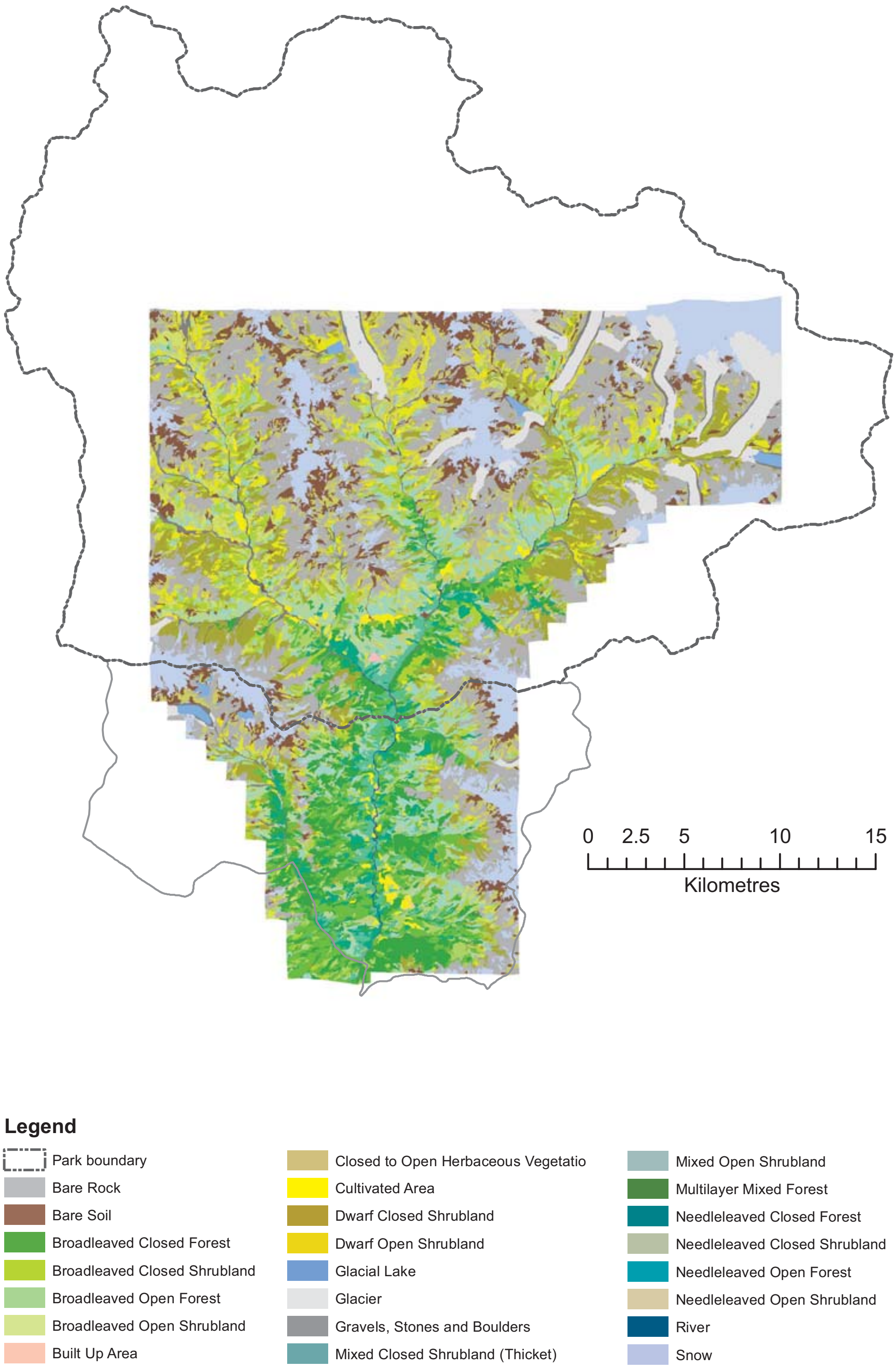


Figure 3.6: Land cover map derived from IKONOS images

soil, glacier and snow classes only. Vegetation types between 5,000 m and 6,000 m are mainly grass (herbaceous vegetation), closed and open dwarf shrubs with some broadleaved and needleleaved shrubs. The cultivated areas are found up to 5,000 m while all the forest covers are located below 4,000 m.

Table 3.3: Summary of land cover from IKONOS Image

Class name	Area (ha)
Bare Rock	16,550
Bare Soil	4,490
Broadleaved Closed Forest	2,725
Broadleaved Closed Shrubland	3,658
Broadleaved Open Forest	960
Broadleaved Open Shrubland	2,461
Built Up Area	32
Closed to Open Herbaceous Vegetation	6,416
Cultivated Area	764
Dwarf Closed Shrubland	6,288
Dwarf Open Shrubland	3,180
Glacial Lake	485
Glacier	3,892
Gravels, Stones and Boulders	1,224
Mixed Closed Shrubland (Thicket)	144
Mixed Open Shrubland	3,995
Multilayer Mixed Forest	3,971
Needleleaved Closed Forest	2,048
Needleleaved Closed Shrubland	2,417
Needleleaved Open Forest	1,263
Needleleaved Open Shrubland	777
River	97
Snow	7,321
Total	75,156

Land cover from ASTER (2006)

The land cover generated from ASTER image of 1 February 2006 (Figure 3.7) showed a forest cover of 6.96% of the SNPBZ area. The shrubs occupied a land cover of 11.86% while the grass covered 5.84%. The bare area including bare rock, bare soil, gravel, stone and boulders occupied 43.69%. Built up and cultivated area covered 0.67%. Glacial lakes covered 0.58% while snow and glaciers covered 30.40%. The details of land cover types by elevation zone are given in Table 3.4.

Land cover from LandSat ETM+ (2000)

The land cover generated from LandSat ETM+ image of 30 October 2000 (Figure 3.8) showed a forest cover of 6.64% of the SNPBZ area. The shrubs occupied a cover of 11.42% while the grass covered 8.26%. The bare area including bare rock, bare soil, gravel, stone and boulders occupied 35.19%. Built up and cultivated area covered 0.73%. Glacial lakes covered 0.61% while snow and glaciers covered 37.15%. The details of land cover types by elevation zone are given in Table 3.5.

Land cover from LandSat TM (1992)

The land cover generated from LandSat TM image of 17 November 1992 (Figure 3.9) showed a forest cover of 7.23% of the total park and buffer zone area. The shrubs occupied a cover of 11.69% while the grass covered 4.5%. The bare area including bare rock, bare soil, gravel, stone and boulders occupied 37.04%. Built up and cultivated area covered 0.69%. Glacial lakes covered 0.42% while snow and glaciers covered 38.44%. The details of land cover types by elevation zone are given in Table 3.6.

Validation and accuracy assessment

Questions concerning accuracy of information are difficult to address in a convincing manner (Campbell 1996). Stehman and Czaplewsky (1998) provide a framework for spatial accuracy assessment. An error matrix is the most commonly used form for reporting site specific accuracy as it effe ctively summarizes the key information obtained from the sampling and response designs. The error matrix represents a contingency table in which the diagonal entries represent correct classifications, or agreement between the map and reference data, and the off-diagonal entries represent misclassifications, or lack of agreement between the map and reference data.

For the validation of the land cover classification, a field mission was carried out from 27 September to 21 October 2007. The data collection was focused mainly on vegetation cover types. Additional data of observation points from the previous field work were also used for validation.

A uniform grid of 500x500 m was generated over the area covered by IKONOS. Fifteen percent (468) points were selected randomly and used for accuracy assessment (Figure 3.10). The land cover at each point was interpreted with the help of IKONOS 4 m Multispectral and 1 m Panchromatic images and available field photographs. These were then compared with the land cover map to calculate the error matrix. The accuracy assessment is provided on Tables 3.7 and 3.8. The accuracy assessments of land cover data derived from ASTER, LandSat ETM+ and LandSat TM are presented in tables 3.9, 3.10 and 3.11 respectively.

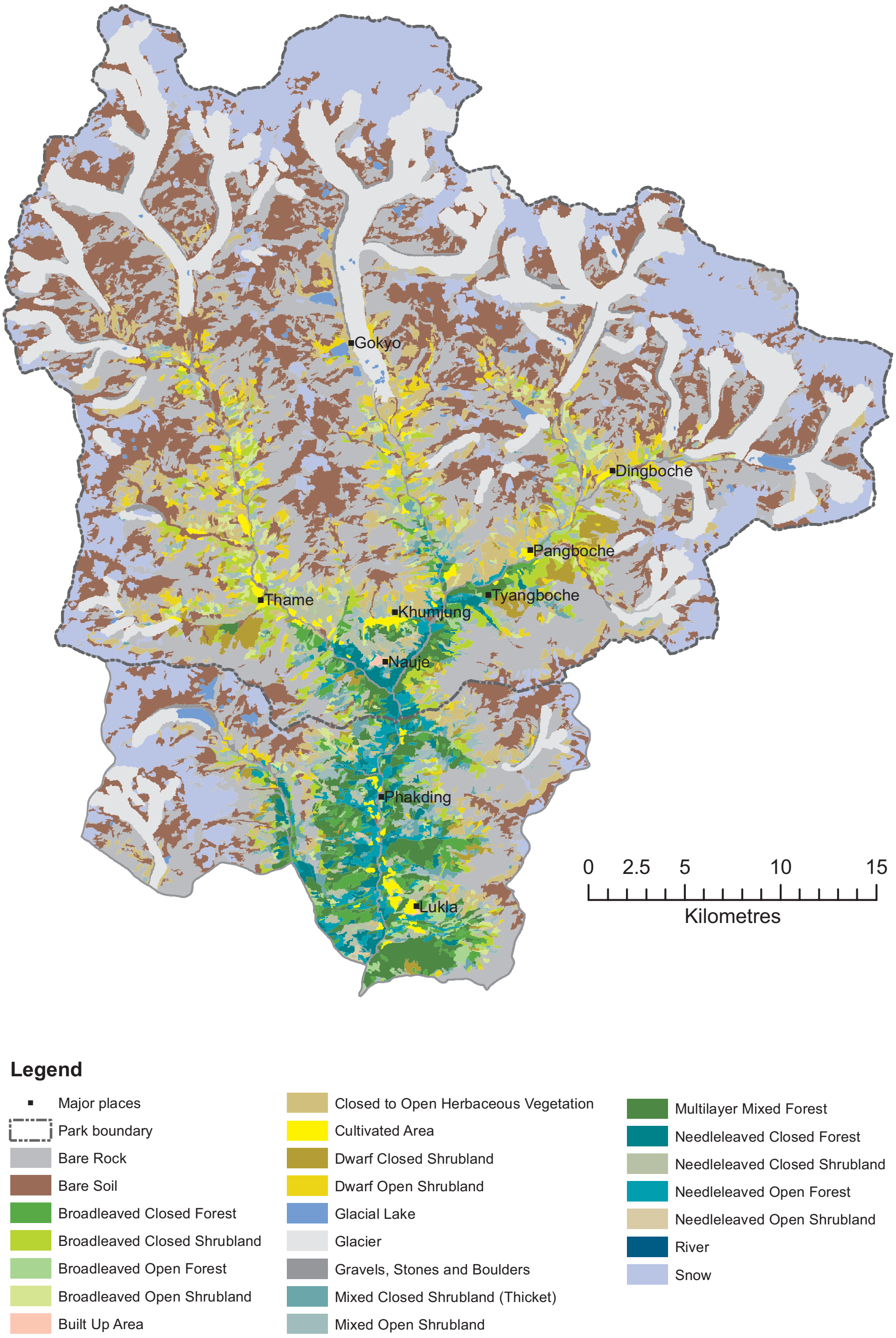


Figure 3.7: Land cover based on ASTER Image, 1 February 2006

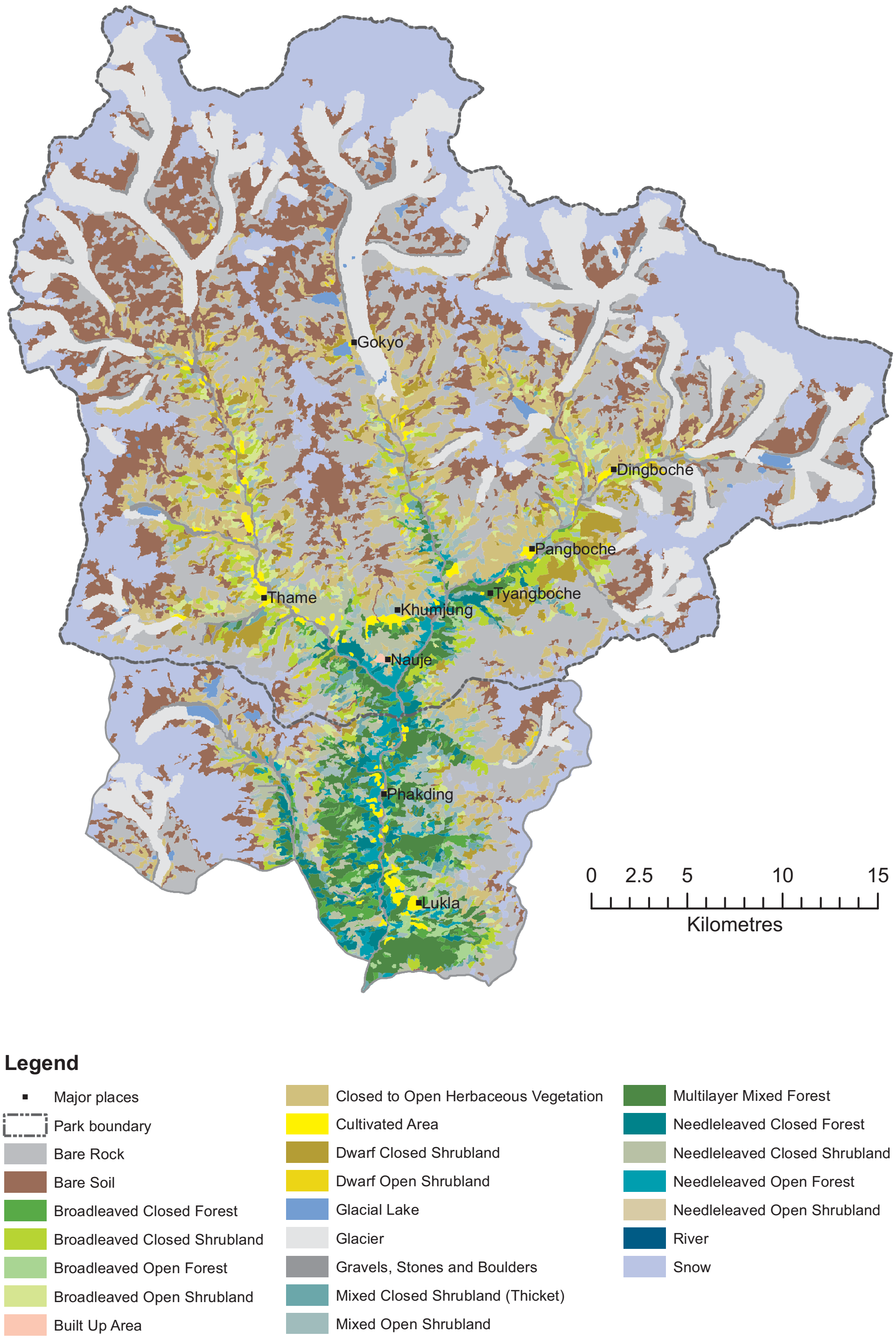


Figure 3.8: Land cover based on LandSat ETM +, 30 October 2000

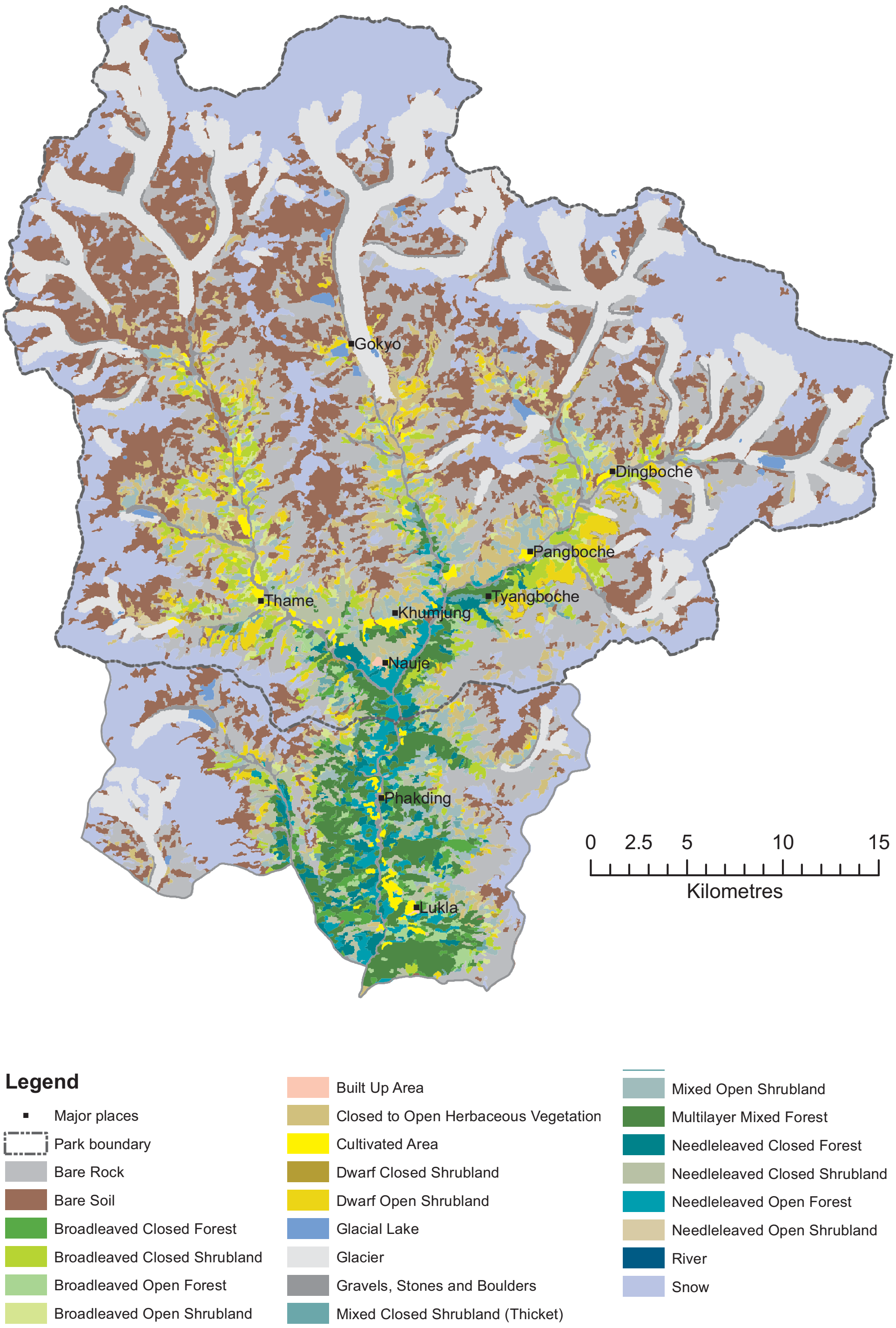


Figure 3.9: Land cover based on LandSat TM, 17 November 1992

Table 3.4: Summary of land cover types by elevation zone (2006)

	Land cover 2006	Elevation zone						
S. No.	Class name	< 2000	2000 – 3000	3000 – 4000	4000 – 5000	> 5000	Total	% of Total (ha)
1	Bare Rock	3	4	142	13,957	17,572	31,677	22.51
2	Bare Soil	0	4	72	4,829	22,594	27,499	19.54
3	Broadleaved Closed Forest	0	344	1,515	62	0	1,921	1.36
4	Broadleaved Closed Shrubland	0	8	841	2,464	0	3,313	2.35
5	Broadleaved Open Forest	4	152	565	47	0	767	0.55
6	Broadleaved Open Shrubland	0	0	145	1,474	0	1,620	1.15
7	Built Up Area	0	11	37	0	0	47	0.03
8	Closed to Open Herbaceous Vegetation	1	34	685	5,800	1,696	8,216	5.84
9	Cultivated Area	0	297	338	259	0	895	0.64
10	Dwarf Closed Shrubland	0	0	307	1,835	39	2,180	1.55
11	Dwarf Open Shrubland	0	0	97	2,063	36	2,196	1.56
12	Glacial Lake	0	0	0	429	393	822	0.58
13	Glacier	0	0	0	4,356	17,354	21,710	15.42
14	Gravels, Stones and Boulders	6	194	353	928	831	2,312	1.64
15	Mixed Closed Shrubland (Thicket)	2	71	410	811	20	1,313	0.93
16	Mixed Open Shrubland	0	44	625	2,566	1	3,235	2.30
17	Multilayer Mixed Forest	4	901	2,618	152	0	3,674	2.61
18	Needleleaved Closed Forest	10	586	1,011	81	0	1,688	1.20
19	Needleleaved Closed Shrubland	0	195	1,489	1,031	0	2,715	1.93
20	Needleleaved Open Forest	4	733	968	44	0	1,749	1.24
21	Needleleaved Open Shrubland	2	35	76	4	0	117	0.08
22	Snow	0	0	0	244	20,835	21,079	14.98
	Total						140,745	100.00

Table 3.5: Summary of land cover types by elevation zone (2000)

	Land cover 2000	Elevation zone						
S. No.	Class name	< 2000	2000 – 3000	3000 – 4000	4000 – 5000	> 5000	Total	% of Total (ha)
1	Bare Rock	0	0	69	12,071	13,203	25,343	17.99
2	Bare Soil	0	0	32	4,311	16,380	20,723	14.71
3	Broadleaved Closed Forest	0	330	1,010	64	0	1,404	1.00
4	Broadleaved Closed Shrubland	0	12	572	2,338	0	2,921	2.07
5	Broadleaved Open Forest	0	224	509	22	0	755	0.54
6	Broadleaved Open Shrubland	0	0	167	1,622	0	1,790	1.27
7	Built Up Area	0	0	26	0	0	26	0.02
8	Closed to Open Herbaceous Vegetation	0	28	507	8,006	3,089	11,629	8.26
9	Cultivated Area	0	332	367	300	0	999	0.71
10	Dwarf Closed Shrubland	0	0	108	3,228	34	3,370	2.39
11	Dwarf Open Shrubland	0	0	3	239	16	257	0.18
12	Glacial Lake	0	0	0	464	394	858	0.61
13	Glacier	0	0	0	4,384	17,375	21,759	15.45
14	Gravels, Stones and Boulders	10	237	535	1,570	1,147	3,498	2.48
15	Mixed Closed Shrubland (Thicket)	7	27	409	477	0	920	0.65
16	Mixed Open Shrubland	1	75	1,146	2,082	0	3,303	2.35
17	Multilayer Mixed Forest	7	990	3,016	144	0	4,158	2.95
18	Needleleaved Closed Forest	5	496	960	73	0	1,533	1.09
19	Needleleaved Closed Shrubland	0	175	2,037	1,185	0	3,397	2.41
20	Needleleaved Open Forest	10	684	763	48	0	1,505	1.07
21	Needleleaved Open Shrubland	0	6	58	64	0	127	0.09
22	Snow	0	0	0	734	29,839	30,573	21.71
	Total						140,849	100.00

Table 3.6: Summary of land cover types by elevation zone (1992)

	Land cover 1992	Elevation zone						
S. No.	Class Name	< 2000	2000 – 3000	3000 – 4000	4000 - 5000	> 5000	Total	% of Total (ha)
1	Bare Rock	0	5	231	10,890	10,757	21,882	15.54
2	Bare Soil	0	0	46	6,888	19,772	26,706	18.96
3	Broadleaved Closed Forest	0	265	876	84	0	1,225	0.87
4	Broadleaved Closed Shrubland	0	9	511	3,020	0	3,539	2.51
5	Broadleaved Open Forest	0	186	501	40	0	727	0.52
6	Broadleaved Open Shrubland	0	2	108	1,119	0	1,229	0.87
7	Built Up Area	0	9	28	0	0	37	0.03
8	Closed to Open Herbaceous Vegetation	7	37	539	4,668	1,091	6,342	4.50
9	Cultivated Area	0	314	346	264	0	924	0.66
10	Dwarf Closed Shrubland	0	0	19	462	31	512	0.36
11	Dwarf Open Shrubland	0	0	78	2,329	49	2,456	1.74
12	Glacial Lake	0	0	0	386	200	586	0.42
13	Glacier	0	0	0	4,354	17,364	21,719	15.42
14	Gravels, Stones and Boulders	8	262	525	1,679	1,108	3,581	2.54
15	Mixed Closed Shrubland (Thicket)	0	5	269	250	0	524	0.37
16	Mixed Open Shrubland	1	29	886	3,470	0	4,386	3.11
17	Multilayer Mixed Forest	7	1,139	3,668	269	0	5,084	3.61
18	Needleleaved Closed Forest	5	487	971	86	0	1,549	1.10
19	Needleleaved Closed Shrubland	0	148	1,816	1,704	0	3,668	2.60
20	Needleleaved Open Forest	11	716	846	28	0	1,601	1.14
21	Needleleaved Open Shrubland	0	3	30	122	0	155	0.11
22	Snow	0	0	0	1,318	31,106	32,423	23.02
Total							140,855	100.00

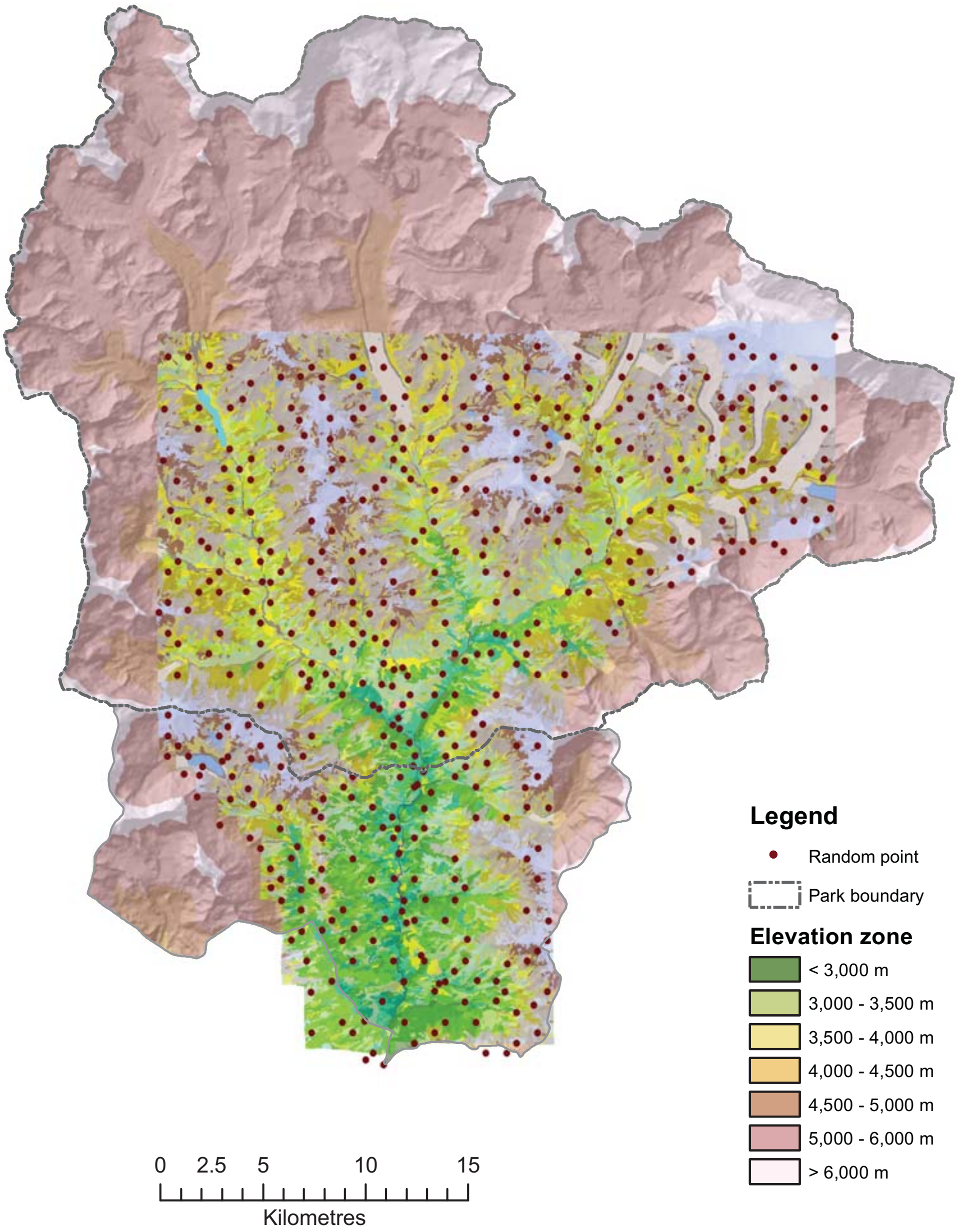


Figure 3.10: Random points for accuracy assessment

Table 3.7: Error matrix of land cover map from IKONOS image

Classified	Bare Rock	Gravels, Stones And Boulders	Bare Soil	Built Up Area	River	Glacial Lake	Snow	Glacier	Cultivated Area	Multilayer Mixed Forest	Needleleaved Closed Forest	Needleleaved Open Forest	Broadleaved Closed Forest	Broadleaved Open Forest	Broadleaved Closed Shrubland	Broadleaved Open Shrubland	Mixed Closed Shrubland	Mixed Open Shrubland	Needleleaved Closed Shrubland	Needleleaved Open Shrubland	Closed to Open Herbaceous Vegetation	Dwarf Closed Shrubland	Dwarf Open Shrubland	**Total**
Bare Rock	98	1	1																				1	101
Gravels, Stones and Boulders		6																						6
Bare Soil		1	32																		1			34
Built Up Area				2																				2
River					5																			5
Glacial Lake						5																		5
Snow							53																	53
Glacier								25																25
Cultivated Area									5															5
Multilayer Mixed Forest										27														27
Needleleaved Closed Forest											10													10
Needleleaved Open Forest												9												9
Broadleaved Closed Forest										3			22						1					26
Broadleaved Open Forest												1		6										7
Broadleaved Closed Shrubland											1				14							1		16
Broadleaved Open Shrubland										1						13							1	15
Mixed Closed Shrubland																	2							2
Mixed Open Shrubland																1		25			1			27
Needleleaved Closed Shrubland																			10					10
Needleleaved Open Shrubland																				6				6
Closed to Open Herbaceous Vegetation	2		4															1			19		2	28
Dwarf Closed Shrubland	5																					24	1	30
Dwarf Open Shrubland	1									1											3		14	19
Total	106	8	37	2	5	5	53	25	5	32	11	10	22	6	14	14	2	26	11	6	24	25	19	468

Table 3.8: Accuracy of totals (IKONOS Image)

Class Name	Reference Totals	Totals Classified	Number Correct	Producer's Accuracy %	**User's Accuracy %**
Bare Rock	106	101	98	92.45	97.03
Gravels, Stones and Boulders	8	6	6	75.00	100.00
Bare Soil	37	34	32	86.49	94.12
Built Up Area	2	2	2	100.00	100.00
River	5	5	5	100.00	100.00
Glacier Lake	5	5	5	100.00	100.00
Snow	53	53	53	100.00	100.00
Glacier	25	25	25	100.00	100.00
Cultivated area	5	5	5	100.00	100.00
Multilayer Mixed Forest	32	27	27	84.38	100.00
Needleleaved Closed Forest	11	10	10	90.91	100.00
Needleleaved Open Forest	10	9	9	90.00	100.00
Broadleaved Closed Forest	22	26	22	100.00	84.62
Broadleaved Open Forest	6	7	6	100.00	85.71
Broadleaved Closed Shrubland	14	16	14	100.00	87.50
Broadleaved Open Shrubland	14	15	13	92.86	86.67
Mixed Closed Shrubland	2	2	2	100.00	100.00
Mixed Open Shrubland	26	27	25	96.15	92.59
Needleleaved Closed Shrubland	11	10	10	90.91	100.00
Needleleaved Open Shrubland	6	6	6	100.00	100.00
Close to Open Herbaceous vegetation	24	28	19	79.17	67.86
Closed Dwarf Shrubland	25	30	24	96.00	80.00
Open Dwarf Shrubland	19	19	14	73.68	73.68
Total	468	468	432		

Overall Classification Accuracy = 92.31%

Table 3.9: Accuracy of totals (ASTER)

Class Name	Reference Totals	Totals Classified	Number Correct	Producer's Accuracy %	User's Accuracy %
Unclassified	0	0	0	---	---
Bare Rock	53	53	46	86.79	86.79
Bare Soil	35	46	32	91.43	69.57
Broadleaved Closed Forest	23	16	16	69.57	100.00
Broadleaved Closed Shrubland	10	16	8	80.00	50.00
Broadleaved Open Forest	1	1	0	0.00	0.00
Broadleaved Open Shrubland	2	0	0	---	---
Built Up Area	1	1	1	100.00	100.00
Closed to Open Herbaceous Vegetation	10	14	5	50.00	35.71
Cultivated Area	6	9	6	100.00	66.67
Dwarf Closed Shrubland	4	5	1	25.00	20.00
Dwarf Open Shrubland	6	7	3	50.00	42.86
Glacial Lake	9	9	8	88.89	88.89
Glacier	75	75	74	98.67	98.67
Gravels, Stones and Boulders	20	19	18	90.00	94.74
Mixed Closed Shrubland (Thicket)	2	3	2	100.00	66.67
Mixed Open Shrubland	11	8	6	54.55	75.00
Multilayer Mixed Forest	20	18	17	85.00	94.44
Needleleaved Closed Forest	11	9	7	63.64	77.78
Needleleaved Closed Shrubland	3	5	2	66.67	40.00
Needleleaved Open Forest	6	8	4	66.67	50.00
Needleleaved Open Shrubland	4	0	0	---	---
Snow	84	74	73	86.90	98.65
Totals	396	396	339		

Overall Classification Accuracy = 83.08%

Table 3.10: Accuracy of totals (LandSat ETM+)

Class Name	Reference Totals	Totals Classified	Number Correct	Producer's Accuracy %	User's-Accuracy %
Unclassified	0	0	0	---	---
Bare Rock	53	49	48	90.57	97.96
Bare Soil	35	40	34	97.14	85.00
Broadleaved Closed Forest	23	14	14	60.87	100.00
Broadleaved Closed Shrubland	10	15	8	80.00	53.33
Broadleaved Open Forest	1	2	1	100.00	50.00
Broadleaved Open Shrubland	2	0	0	---	---
Built Up Area	1	1	1	100.00	100.00
Closed to Open Herbaceous Vegetation	10	21	6	60.00	28.57
Cultivated Area	6	10	6	100.00	60.00
Dwarf Closed Shrubland	4	6	2	50.00	33.33
Dwarf Open Shrubland	6	0	0	---	---
Glacial Lake	9	9	9	100.00	100.00
Glacier	75	75	75	100.00	100.00
Gravels, Stones and Boulders	20	25	20	100.00	80.00
Mixed Closed Shrubland (Thicket)	2	0	0	---	---
Mixed Open Shrubland	11	10	6	54.55	60.00
Multilayer Mixed Forest	20	18	17	85.00	94.44
Needleleaved Closed Forest	11	10	8	72.73	80.00
Needleleaved Closed Shrubland	3	5	2	66.67	40.00
Needleleaved Open Forest	6	4	4	66.67	100.00
Needleleaved Open Shrubland	4	1	1	25.00	100.00
Snow	84	81	81	96.43	100.00
Totals	396	396	343		

Overall Classification Accuracy = 86.62%

Table 3.11: Accuracy of totals (Landsat TM)

Class Name	Reference Totals	Totals Classified	Number Correct	Producer's Accuracy %	User's Accuracy %
Unclassified	0	0	0	---	---
Bare Rock	53	44	43	81.13	97.73
Bare Soil	35	42	35	100.00	83.33
Broadleaved Closed Forest	23	12	12	52.17	100.00
Broadleaved Closed Shrubland	10	15	9	90.00	60.00
Broadleaved Open Forest	1	2	1	100.00	50.00
Broadleaved Open Shrubland	2	0	0	---	---
Built Up Area	1	1	1	100.00	100.00
Closed to Open Herbaceous Vegetation	10	12	6	60.00	50.00
Cultivated Area	6	9	6	100.00	66.67
Dwarf Closed Shrubland	4	0	0	---	---
Dwarf Open Shrubland	6	9	3	50.00	33.33
Glacial Lake	9	9	9	100.00	100.00
Glacier	75	75	75	100.00	100.00
Gravels, Stones and Boulders	20	23	20	100.00	86.96
Mixed Closed Shrubland (Thicket)	2	3	0	0.00	0.00
Mixed Open Shrubland	11	9	7	63.64	77.78
Multilayer Mixed Forest	20	20	18	90.00	90.00
Needleleaved Closed Forest	11	10	8	72.73	80.00
Needleleaved Closed Shrubland	3	6	2	66.67	33.33
Needleleaved Open Forest	6	5	4	66.67	80.00
Needleleaved Open Shrubland	4	1	1	25.00	100.00
Snow	84	89	83	98.81	93.26
Totals	396	396	343		

Overall Classification Accuracy = 86.62%

Land cover change assessment

For the land cover change analysis, land covers were derived from LandSat TM (17 November 1992) and ASTER (1 February 2006) images. The same land cover classes were used for the classification. Although the spatial details were coarser than the interpretation from IKONOS images, these images covered the entire park and buffer zone and provided an overall picture of the area.

More than 70% of the SNPBZ area is covered with snow and ice, glaciers, bare rocks and bare soil. The variations in aspect and slope influence the local vegetation, but the altitude and its influence on climatic conditions have dominated the distribution pattern of vegetation in SNPBZ. Therefore, the land cover classes have been presented with their distribution in different elevation zones. The change analysis has also been carried out for each elevation zone so that they can be better linked with other influences of socioeconomic activities.

The changes in each class by elevation zone are presented in Table 3.12. Changes in aggregated classes are shown in Table 3.13. Change in forest cover is presented in figure 3.11. There is a decrease in forest area by 387 ha and an increase in shrub area by 220 ha. The decrease in forest area is high in elevations between 3,000 m to 5,000 m. The shrub area showed an increase in 3,000–4,000 m elevation zone while a decrease in 4,000–5,000 m elevation zone. Grass and bare areas have increased by 1,874 ha and 9,320 ha, respectively. The increase in grass area is highest in 4000-5000 m elevation zone. There is a small increase in built area while a decrease in cultivated area. Glacial lake has increased by 236 ha while glaciers have decreased in area. The maximum change is seen in snow cover which amounted to 11,344 ha.

The analysis presents the detailed area of different land cover types and their changes over time. However, it should be kept in mind that the sources of land covers are from two different satellite images with different sensors that provide a snapshot of the day when the image is captured. Also the times of the year when these images are taken are different - one at the beginning of winter and the other at the end of winter. Therefore, there are inherent limitations in the interpretation of changes, mainly in vegetation and snow covers. There are slight differences in total areas of the three analyses that occurred due to re-sampling of the layers and differences in pixel origins of the images.

Table 3.12: Land cover change by elevation zones between 1992 to 2006

	Change between 1992 and 2006	Elevation zone					
S.No.	Class Name	< 2000	2000 – 3000	3000 – 4000	4000 - 5000	> 5000	Total (ha)
1	Bare Rock	3	-1	-89	3067	6815	9795
2	Bare Soil	0	4	27	-2059	2822	793
3	Broadleaved Closed Forest	0	79	639	-23	0	695
4	Broadleaved Closed Shrubland	0	-1	330	-555	0	-226
5	Broadleaved Open Forest	4	-34	63	7	0	40
6	Broadleaved Open Shrubland	0	-2	37	355	0	390
7	Built Up Area	0	2	9	0	0	10
8	Closed to Open Herbaceous Vegetation	-6	-3	146	1132	605	1874
9	Cultivated Area	0	-17	-8	-5	0	-29
10	Dwarf Closed Shrubland	0	0	287	1373	7	1668
11	Dwarf Open Shrubland	0	0	19	-266	-14	-260
12	Glacial Lake	0	0	0	43	193	236
13	Glacier	0	0	0	2	-11	-9
14	Gravels, Stones and Boulders	-2	-67	-172	-751	-277	-1269
15	Mixed Closed Shrubland (Thicket)	2	65	141	561	20	789
16	Mixed Open Shrubland	-1	15	-262	-904	1	-1151
17	Multilayer Mixed Forest	-4	-238	-1050	-117	0	-1409
18	Needleleaved Closed Forest	5	99	41	-5	0	139
19	Needleleaved Closed Shrubland	0	48	-327	-673	0	-953
20	Needleleaved Open Forest	-7	17	122	16	0	148
21	Needleleaved Open Shrubland	2	32	46	-118	0	-38
22	Snow	0	0	0	-1073	-10271	-11344

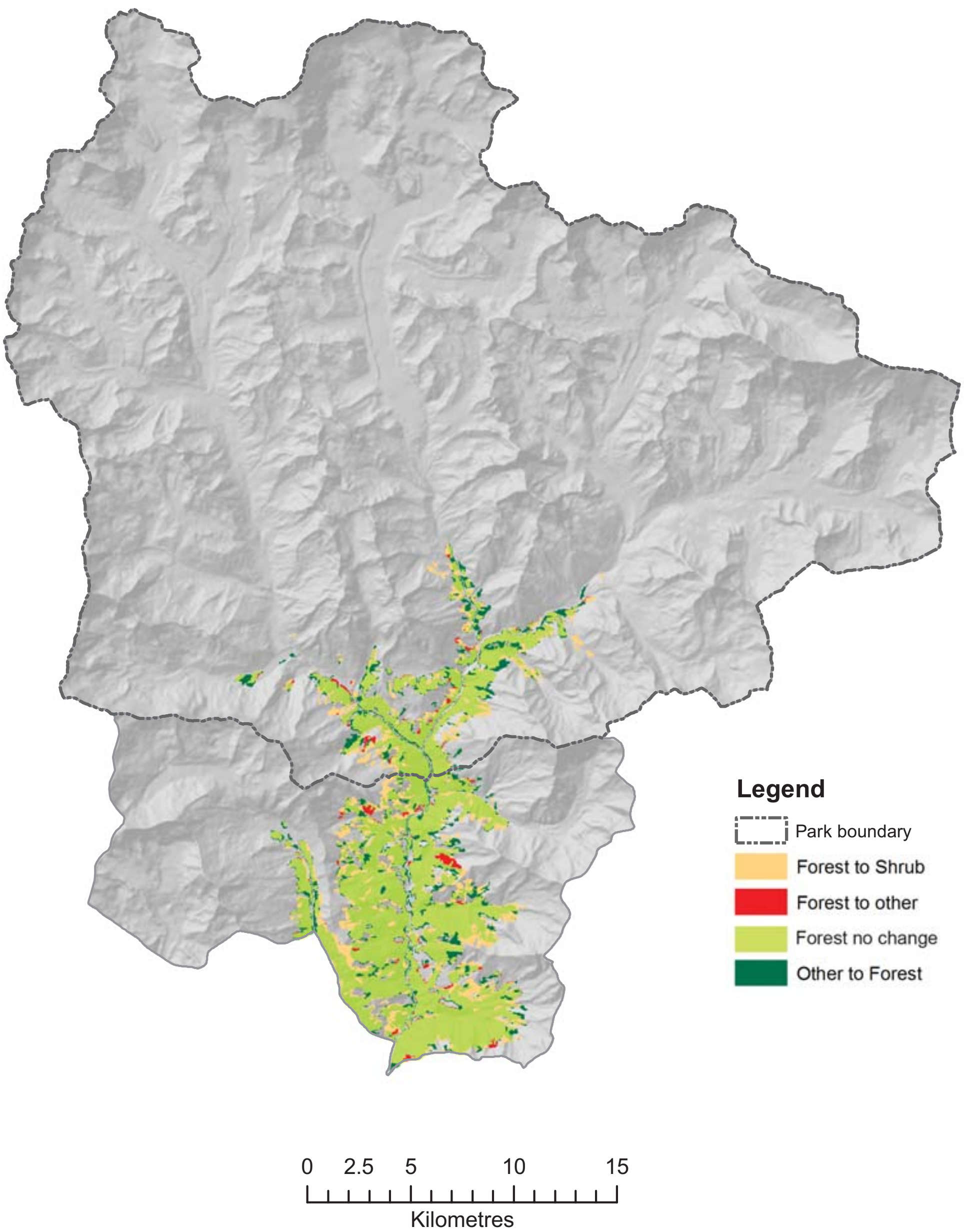


Figure 3.11. Change in forest cover (1992- 2006)

Table 3.13: Land cover change (aggregated) by elevation zones between 1992 to 2006

		Elevation zone					
	Change from 1992 to 2006 (aggregated)	< 2000	2000 – 3000	3000 – 4000	4000 – 5000	> 5000	Total (ha)
1	Forest	-2	-77	-186	-122	0	-387
2	Shrub	3	157	272	-227	14	220
3	Grass	-6	-3	146	1132	605	1874
4	Bare area	0	-64	-234	257	9361	9320
5	Built Up Area	0	2	9	0	0	10
6	Cultivated Area	0	-17	-8	-5	0	-29
7	Glacial Lake	0	0	0	43	193	236
8	Glacier	0	0	0	2	-11	-9
9	Snow	0	0	0	-1073	-10271	-11344


Birendra Bajracharya

4

Land Cover Mapping of the Central Karakoram National Park (CKNP)

Study area

The CKNP (Figure 4.1), located in the far north of Pakistan, is an extremely rugged area in Karakoram range that shares international boundaries with India in the east and China in the north. Azad Jammu Kashmir (AJK) and North Western Frontier Province (NWFP) are its neighboring territories within the country. The CKNP extends from 35°N to 36.5°N Latitude and from 74°E to 77°E Longitude. The area constitutes of high mountains, large glaciers, rugged valleys and harsh rivers. The CKNP represents the largest source of freshwater for Pakistan and one of the largest mountain glacial systems in the world, with Siachen (75 km long), Baltoro (57 km), and Hispur-Biafo (122 km) glaciers all originating within the park boundaries.

The CKNP is also the largest national park in Pakistan, covering an area of 12,000 sq km. The park was established to protect the flora and fauna of the area in its natural state. Since the revised boundary of the national park is still under discussion, watershed boundaries of all the relevant valleys (Table 4.1) were delineated using 30 m resolution DEM. On the southern part, Indus River is taken as the boundary of the study area.

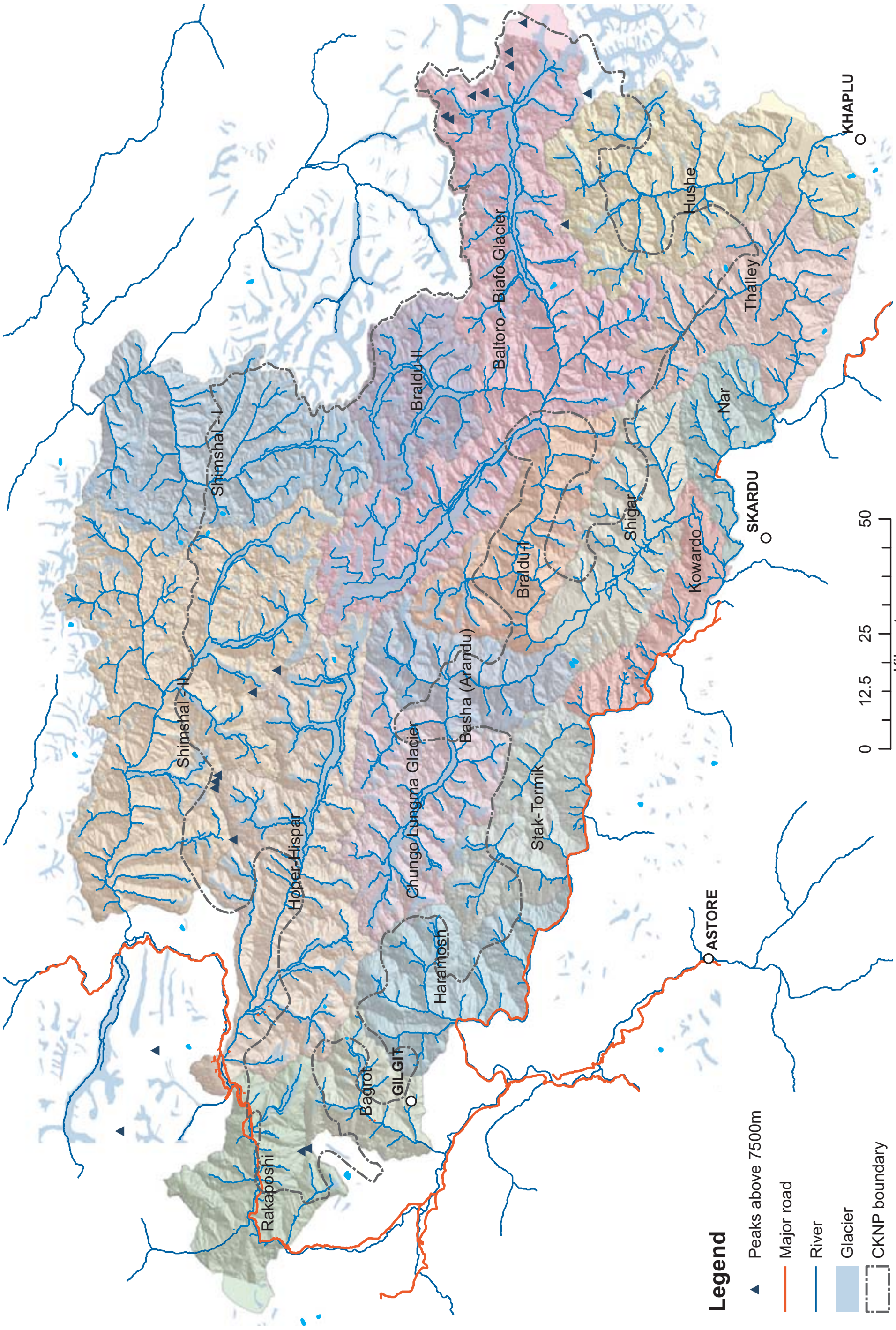


Figure 4.1: Map of CKNP with major valleys

Table 4.1: List of valleys of study area

Sr. No.	Valley Name	Area (sq km)
1	Shimshal - I	1,504
2	Shimshal - II	2,729
3	Rakaposhi	613
4	Hopar-Hispar	1,856
5	Bagrot	432
6	Braldo - I	884
7	Braldo-II	671
8	Hushe	1,660
9	Thalley	1,006
10	Haramosh	821
11	Baltoro - Biafo Glaciers	2,864
12	Basha (Arandu)	615
13	Chungo Lungma Glacier	1,012
14	Stak-Tormik	806
15	Shigar	895
16	Nar	398
17	Kowardo	431
	Total	19,197

Climate

The climate of the area is predominantly cold arid while it is temperate at the lower elevations. The climatic variation in the area is greatly influenced by altitudinal differences. Lower altitudes (below 2,300 m) experience marked diurnal as well as seasonal temperature variations and scanty precipitation. The areas between 2,300 m and 3,300 m receive sufficient snow and enjoy a temperate climate. Areas above 3,300 m are very cold with a limited growth season. Most of the areas are beyond the reach of summer monsoon rainfall. Average rainfall in the valleys is 100-300 mm, most of which occurs during the winter and early spring.

The spatial patterns of distribution and the functioning of land cover types are predominantly determined by climate; principally the factors of precipitation and temperature, whose effects are modified by soil factors. Climatograms (Figure 4.2 and 4.3) drawn from the 36 years data (1970 – 2006) observed from two longitudinal extremes of the study area (Gilgit-74°25’ and Skardu-75°40’) explains the seasonal and spatial variations in the climate.

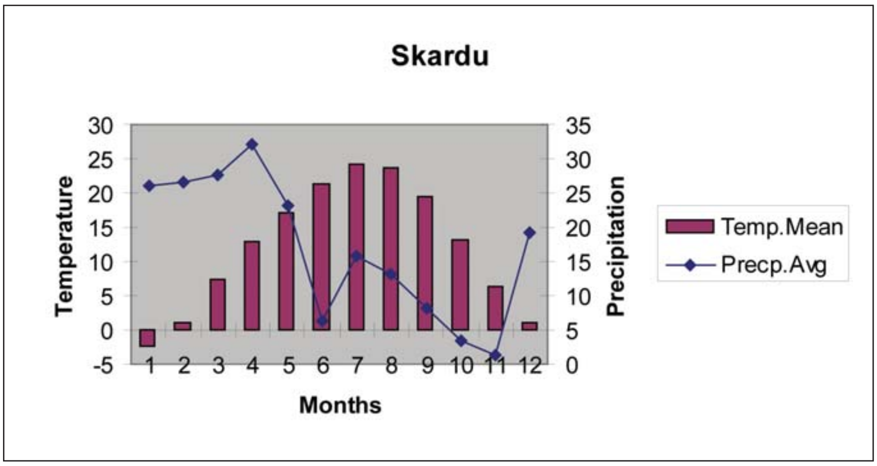


Figure 4.2: Climatogram of Skardu (eastern end of CKNP)
(data source: Pakistan Metrological Department).

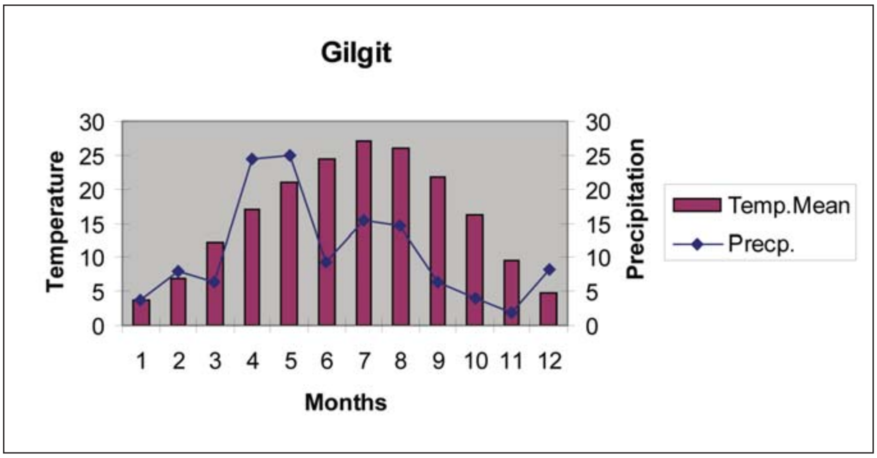


Figure 4.3: Climatogram of Gilgit (western end of CKNP)
(data source: Pakistan Metrological Department).

Ecology

According to Rao and Marwat (2003), based on ecological zones (Figure 4.4), there are four main types of forests in the CKNP area: Montane Dry Temperate Coniferous, Montane Dry Temperate Broadleaved, Sub-Alpine and Northern Dry Scrub.

Montane dry temperate coniferous forests

This zone contains dry deodar (*Cedrus deodara*), blue pine (*Pinus wallichiana*), fir (*Abies spectabilis*), spruce (*Picea smithina*), chilgoza (*Pinus gerardiana*) and juniper (*Juniperus spp*), both in pure or mixed stands. All the important coniferous forests are found in this zone.

Montane dry temperate broadleaved forests

Broadleaved species are found in pockets within the temperate coniferous zone. The main species in this zone include oak (*Quercus ilex*), ash (*Fraxinus spp*.), poplar (*Populus*), willow (*Salix*) and Artemisia.

Sub-alpine forests

This zone has the highest snowfall in the Northern Areas with up to 3 m/year, but gets little rainfall. Plant species found in this zone include birch, willow, juniper, *Ephedra, Vibernum, Andropogon, Berbris, Lonicera* and *Ribes.*

Northern dry scrub

This is scattered scrub vegetation. Rivers and nullahs support seabuckthorn and willow species. Scattered and stunted juniper trees also grow on hillsides.

Rangelands of CKNP are classified as alpine pastures, shrubs, and grasses/forbs. Alpine pastures are found above 3500 m. They are characterized by short, cool growing seasons and long, cold winters. Vegetation mainly consists of perennial, herbaceous plants and shrubs along with mosses and lichens. Shrub species include *Juniperus communis, Rosa webbiana, Berberis lycium, Berberis spp*. Grass species include *Phleum alpinum, Agrostist gigantean, Trisetum spp. Agropyrom dentatum, Agropyron caninum, Fesruca alpoecurus gigantean, Dactylis glomerata ,Pennisetum lanatum, P. filaccidum, Clamagrostis pseudopharg mites, Oryzopsis spp.*

The study area harbours a great faunal diversity that has emerged mainly from four bio-geographical provinces (Palaearctic Realm – Pamir – Tain Shan and Tibetan). At least nine large mammal species including Markhor, Himalayan ibex, Ladakh urial, Blue sheep, Marco Polo sheep, Snow leopard, Himalayan brown bear, Black bear and Himalayan lynx are found in this area.

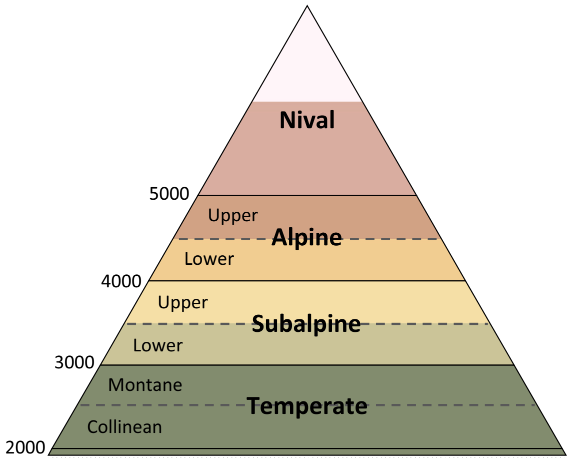


Figure 4.4. Ecological zones and elevations ranges

Population

According to the 1998 census, there are 350 settlements (permanent and non-permanent) and total population of these settlements is approximately 211,000. The settlement pattern is shown in Figure 4.5.

Table 4.2: Population distribution of the study area

District	Tehsil	No. of Settlements within study area	Population
Skardu	Skardu	5	1,700
	Shigar	90	40,035
	Rondhu	50	16,710
Ghance	Doghani	39	15,850
	Khaplu	29	17,500
	Thagas	22	31,420
	Daghoni	1	1,700
	Mashbrum	3	240
Gilgit	Gilgit	46	32,700
	Nagar - 2	11	10,500
	Nagar - 1	26	18,670
	Hunza - 1	24	23,250
	Hunza - 2	4	1,200
Total		350	211,475

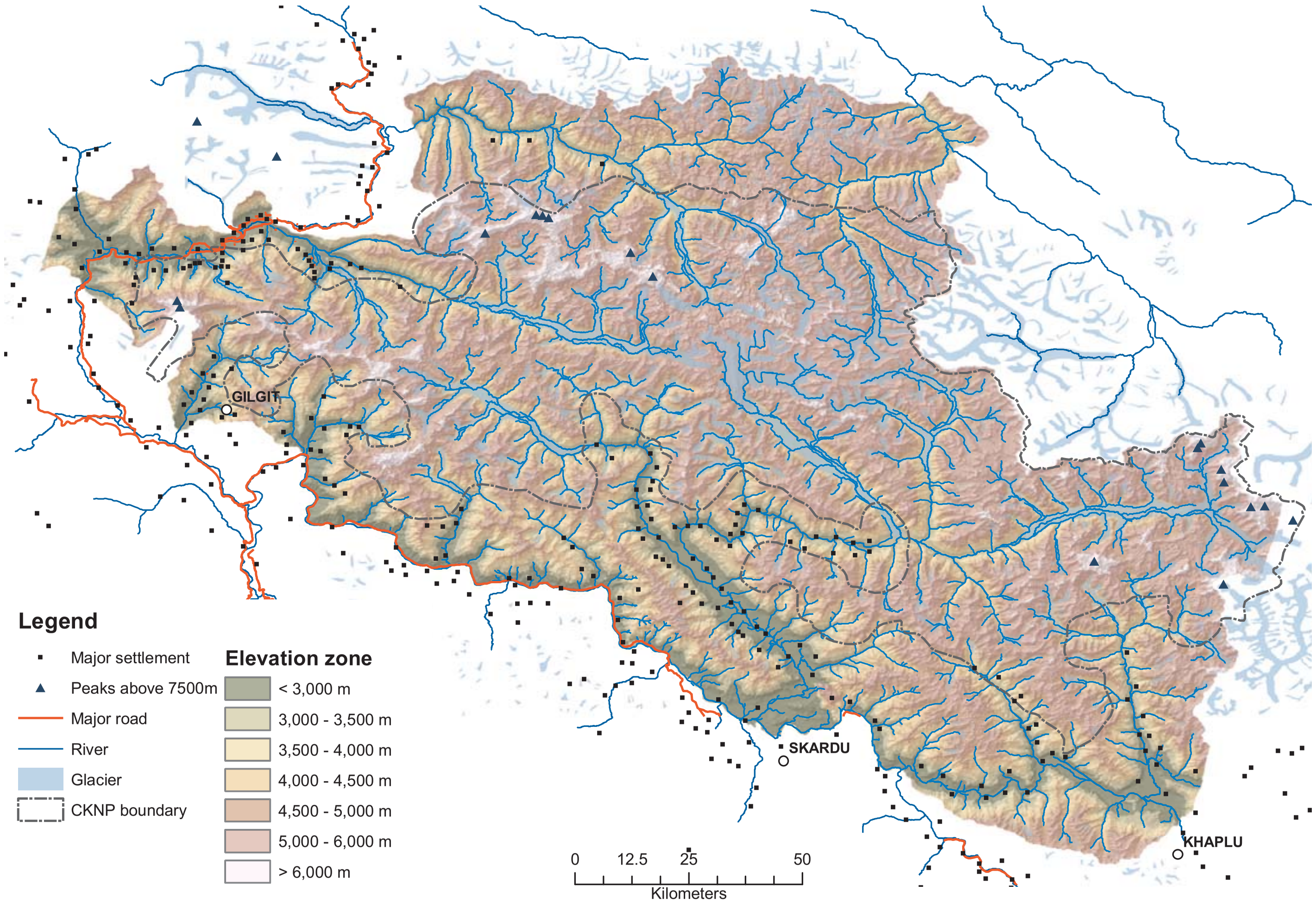


Figure 4.5. Settlement pattern in and around the study area

Previous land cover mapping initiatives

In 1992, Forestry Sector Master Plan (FSMP) was conducted to provide policy guidelines for the national development of forestry in Pakistan, prepared jointly by the Ministry of Food, Agriculture and Cooperatives and a team of consultants from Reid, Collins and Associates/Silviconsult Ltd., under the technical assistance provided by the Asian Development Bank and the UNDP (Reid, Collins and Associates 1992). National level land cover map was prepared using satellite images and extensive field surveys. Interpretation of LandSat-5 satellite images was carried out to map forest cover and land use in Pakistan. A digital catalogue of this forest cover/land use map was developed at the end of the study, identifying 27 land cover classes like Conifer Forest, Riverine Forest, Range-land, Urban areas, etc. Only a part of CKNP area is classified under this study. Further areas of eastern side could not be classified due to unavailability of appropriate base map. Most of the central part of the park was considered as above tree line (1,200 ft) due to use of low resolution DEM dataset.

In year 2001, WWF-Pakistan developed an ecological classification of major land cover types in project areas of Mountain Areas Conservancy Project (MACP). LandSat TM satellite images were used for land cover mapping (WWF-Pakistan 2001). The study covered four distinct conservancies, spread over 16,300 sq km including Nanga Parbat, Gojal, Tirichmir and Qashqar. A small part of the CKNP is covered under the Gojal Conservancy.

In 2004, National Forest and Range Resources study was conducted by the Pakistan Forest Institute, Peshawar (PFI 2004). In this study, Northern Areas of Pakistan was classified only in two classes: Conifer Forest and Rangeland. This study also has study extent limitation similar to FSMP study.

CKNP legend definition

A draft legend for land cover classes of CKNP was developed during a consultative workshop held in Karakoram University in Gilgit. The legend was further modified after the detailed field visit of ground-truthing data collection and preliminary analysis of satellite images of the study area. A suitable legend that can integrate available digital data and ground situation was developed using FAO's LCCS software. The legend developed for CKNP is given in Table 4.3.

Field data collection

An extensive field survey was carried out throughout CKNP in June 2008 using LCCS data encoding forms and Global Positioning System (GPS) receivers. The survey was performed in order to obtain accurate locational point data for each land use and land cover class included in the classification scheme. Due to the large area of CKNP, three teams were configured to survey the three representative areas of CKNP, namely Bagrot Valley, Astak Nullah and Shigar Valley. Each team spent 7 days in the field and collected the ground data from their respective areas. A total of 16 different field investigation trips were made. Before each field investigation trip, mission pre-planning was conducted to ensure successful data collection. A total of 57 sample plots (100 x 100 m) and 209 GPS-linked descriptive data points with 500 photographs from all locations were taken. A2 sized field maps of ASTER satellite data using False Colour Composites (FCC) of band 3 2 1 (RGB) at 1:150,000 and 1:100,000 scales, with geographic grid of 5 minute intervals, were used during the survey. Locations of field data points are shown in Figure 4.6.

Table 4.3: LCCS legend for CKNP

LCCS Code	LCCS Level	LCCOwnLabel	LCCLabel	Own Label
8006	A2B1	Snow	Perennial Snow	Snow
8008-9	A3-A6	Glacier	Ice (Moving)	Glacier
6002-1	A3-A7	Bare Rock	Bare Rock(s)	Rocks
6005-7	A5-A13	Bare Soil	Very Stony Bare Soil And/Or Other Unconsolidated Material(s)	Soil
8001-1	A1-A4	Water	Natural Waterbodies (Flowing)	Water
20021-1	A4A11-A12	Dwarf Open Shrubland	Open (70-60) - 40%) Shrubs (Shrubland)	Shrubs
21454	A2A20B4	Closed to Open Herbaceous Vegetation	Herbaceous Closed to Open Vegetation	Grasses
20175	A4A11B3XXD2	Needleleaved Open Shrubland	Needleleaved Shrubland	Junipers
20133	A3A11B2XXD2	Needleleaved Open Forest	Needleleaved Woodland	Conifers
20088	A3A10B2XXD1	Braodleaved Closed Forest	Broadleaved Closed Trees	Broadleaves
10001	A1-W7	Broadleaved Plantation	Tree Crop(s)Crop Cover: Plantation(s)	Plantation
10025	A3	Cultivated Area	Herbaceous Crop(s)	Agriculture

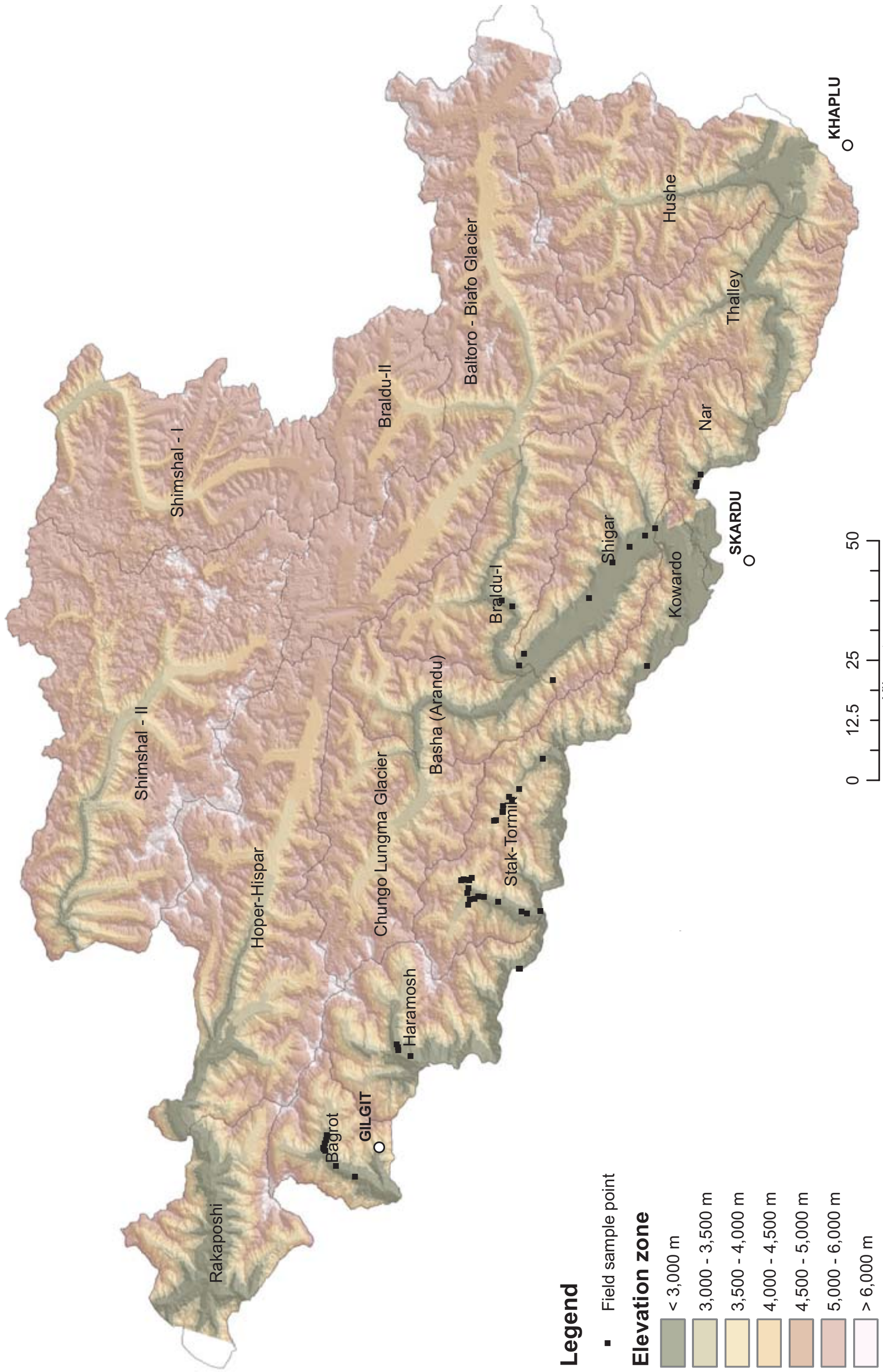


Figure 4.6: Location of field data collection points

Field examples of land cover classes

Snow Glaciers

Bare Rock

Bare Soil

Water

Dwarf Open Shrubland

Closed to Open Herbaceous Vegetation

Needle leaved Open Shrubland

Needle leaved Open Forest


Broad leaved Closed Forest


Broadleaved Plantation


Cultivated Area

Figure 4.7: Examples of land cover classes from the field

Materials and methods

Level 1A ASTER satellite images (Table 4.4) were acquired from its archive of year 2006. ASTER products provide 14 spectral bands, three in the visible and NIR (0.52-0.86 μm), six in the SWIR (1.60-2.43 μm) and five in the thermal infrared bands (8.12-11.65 μm) (Yamaguchi et al. 1998).

Object-based image analysis method is adopted for land cover mapping of the CKNP. Difiniens® software was used for object-based analysis. A similar methodology as used in SNPBZ was followed. Usual process for classification task in Definiens® software may be described by the following steps (Definiens 2006):

- The first phase is *image segmentation* in which meaningful image objects are created that corresponds to objects of interest.
- In the next step, these generated image objects are classified using primary object features such as color (spectral features), texture, shape and context
- And lastly, neighboring image objects of similar class may be aggregated further to produce one larger image object.

Table 4.4: List of ASTER images used in image interpretation

	Scene ID	Acquisition Date	Cloud Cover	Locality
1	32637	26/07/2006	Less than 10%	Shigar, Braldu, Thalley
2	32642	11/03/2006	Less than 10%	Shimshal
3	13974	31/03/2006	Less than 10%	Haramosh, Stak-Tormik
4	32457	24/06/2006	Less than 10%	Shigar, Braldu, Thalley
5	7682	13/03/2006	Less than 10%	Baltoro
6	6511	17/06/2006	Less than 10%	Basha(Arandu), Braldu
7	328	16/05/2006	Less than 10%	Shigar, Braldu, Thalley
8	2200	11/03/2006	Less than 10%	Hisper
9	2199	11/03/2006	Less than 10%	Haramosh, Stak-Tormic
10	2201	11/03/2006	Less than 10%	Shimshal
11	329	16/05/2006	Less than 10%	Biafo

Results and discussion

Figure 4.8 shows the classification results of CKNP and Table 4.5 describes the area of each of the 12 land cover classes.

The area of the park mostly consists of huge mountains with snow covered peaks, ravines, valleys and *nullahs*. With respect to vegetation, most of the area can be characterized as dry alpine scrub type vegetation with species like *Artemesia spp*., *Juniper spp*., *Rosa webbiana* and *Polygonum spp*. on the dry slopes and *Myricaria germanica* and *Hippophae rhamnoides*, along the stream beds. Broadleaves mainly consist of *Salix spp* and *Betula utilis* that can be found in moist places. Conifer Forest mainly includes *Pinus wallichiana* and Junipers. Juniper was found mixed with grasses at high altitude while *Pinus wallichiana* was less common in the area and was mostly found in western end of the CKNP.

Most of the cultivated area and major settlements are along the major river beds of Indus and Shigar rivers. Major crops of the area include wheat, maize and potato while apricot and pomegranate are the major fruit trees of the orchards. Poplar plantation is very common within the cultivated areas and also as separate plantation for domestic timber use.

In the study area two distinct landscapes were observed on the eastern and western extremes. In the eastern side there were very few coniferous forest patches, in lower elevation *Artemesia spp*. shrub was dominant and on higher elevations *Juniper spp.* scrub was the dominant vegetation. In western side there were fairly large patches of

Coniferous forest and *Artemesia spp*. Shrub was less common than in the eastern areas. This difference in vegetation pattern can be related to their respective climate differences. The only source of precipitation in the eastern part is snow fall during the winter season where as in the western areas rain fall during the summer season is also a contributing precipitation factor.

It was observed that during the classification process some of the objects, usually smaller in size, remained unclassified due to the insufficient ground sample collected from the field. These objects were annotated manually after a thorough discussion with the field team members.

The satellite images were of winter season where snow cover was very high in Hisper and Haramosh Valleys. Due to this, the high altitude vegetation e.g., Juniper scrub and grasses could not be mapped in these areas. The high snow cover in these images also caused problems while making mosaics with adjacent areas as it appeared that the snow suddenly changed into vegetation or bare areas.

Due to the very large study area and the use of medium resolution satellite image (e.g. ASTER) it was not possible to describe the land cover in detail. The use of high resolution satellite images for the detailed species level vegetation mapping and glacial mapping of high altitude areas is highly recommended. Furthermore, terrain analysis should also be carried out to document the micro environment of vegetation types in the area.

Table 4.5. Summary of land cover classes in CKNP

Class name	Total Area (ha)
Glaciers	274,068
Snow	919,622
Broad Leaved Closed Forest	1,333
Closed to Open Herbs	142,125
Dwarf Open Shrubs	75,080
Needle Leaved Open Forest	12,240
Needle Leaved Open Shrubland	12,894
Bare Rocks	380,097
Cultivated Areas	14,937
Bare Soil	29,507
Broad Leaved Plantation	1,051
Water	9,936
Total	1,872,890

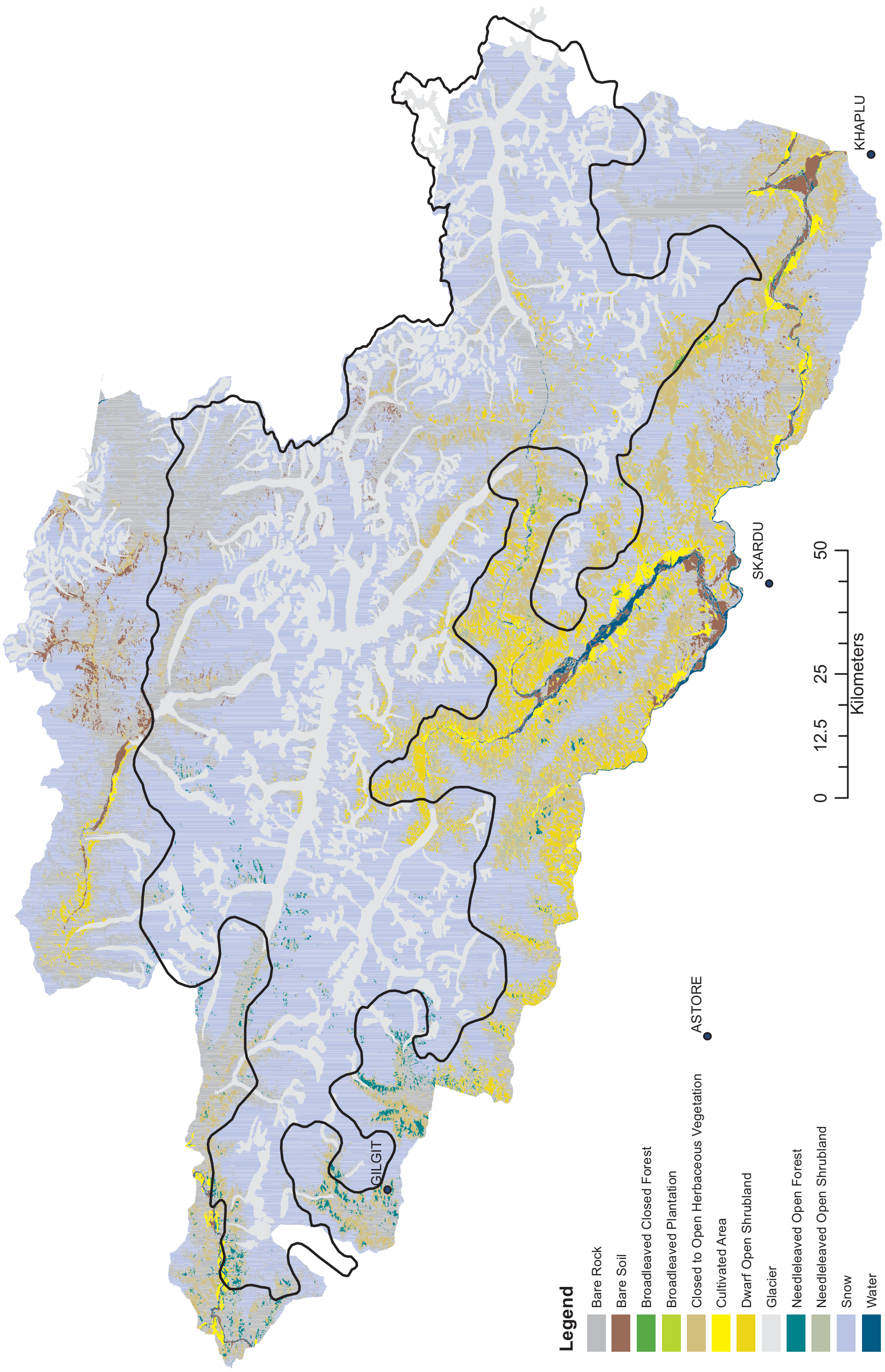


Figure 4.8 Land cover of CKNP

Accuracy assessment

A part of the field data collected during the ground truthing exercise was used for accuracy assessment. In total, 107 sample plots were taken to compile confusion matrix for calculation of accuracy. Since the focus of the study was vegetation and it was not possible to access high altitude glacial/snow areas, only seven vegetation classes were assessed for the accuracy of land cover. The method to calculate accuracies of individual classes and overall accuracy of land cover map is shown in Table 4.6. Over all accuracy of the vegetation classes of the final land cover map is 82.7%.

Table 4.6: Confusion matrix for accuracy assessment

	Broad Leaved Closed Forest	Broad Leaved Plantation	Closed to Open Herbs	Cultivated Areas	Dwarf Open Shrubs	Needle Leaved Open Forest	Needle Leaved Open Shrubland	Shrubs	Total
Broad Leaved Closed Forest	5	1	1						7
Broad Leaved Plantation		7	1	1					9
Closed to Open Herbs			18				2		20
Cultivated Areas			2	17		1			20
Dwarf Open Shrubs				2	15				17
Needle Leaved Open Forest						10	2		12
Needle Leaved Open Shrubland			3				12		15
Total	5	8	26	20	15	11	16	6	107

Large scale mapping of Bagrot and Shigar valleys

As part of the multi-scale approach of using remote sensing data for land cover mapping of CKNP, large scale (detailed level) land cover maps for Bagrot and Shigar valleys (Figure 4.9) have been developed.

Objectives of this multi-scale study were to:

- arrive at an understanding of dynamics of a selected valley in the CKNP buffer zone area and use these information to interpret keys for the regional mapping;
- develop a methodology for an integrated case study that can be applied in future research in other locations within the CKNP and beyond;
- support the development of the CKNP Management Plan.

Bagrot Valley: Bagrot Valley is approximately 17 km southeast of Gilgit town. The lower section of the valley is narrow, with barren slopes and a few settlements. The central part is characterized by large flat plains, and is more densely populated and cultivated. Past the Hinarchi glacier, the upper reaches of Bagrot Valley are wide enough to be used for seasonal cultivation.

Shigar Valley: The Shigar Valley is approximately 15 km northeast of Skardu, and is also a part of the Skardu district. The largest settlements in the valley are Shigar (a collection of numerous smaller villages), Alchori, and Gulabpur. Mostly settlements in the valley are located near the river. The Shigar Valley is the gateway to major trekking destinations such as Concordia, K2, Skoro La (pass) and the Baltoro Glacier, among others.

Satellite image acquisition and pre-processing

SPOT 5 satellite images were used in this study. There are four multi-spectral bands (i.e. NIR, red, green, and SWIR) with 10 m spatial resolution and one panchromatic band with 2.5 m spatial resolution (wavelength ranges from 0.51 to 0.73 μm) for SPOT 5 image.

Two multi-spectral and panchromatic satellite images were procured for Shighar and Bagrot Valleys. Satellite data characteristics are given in the Table 4.7.

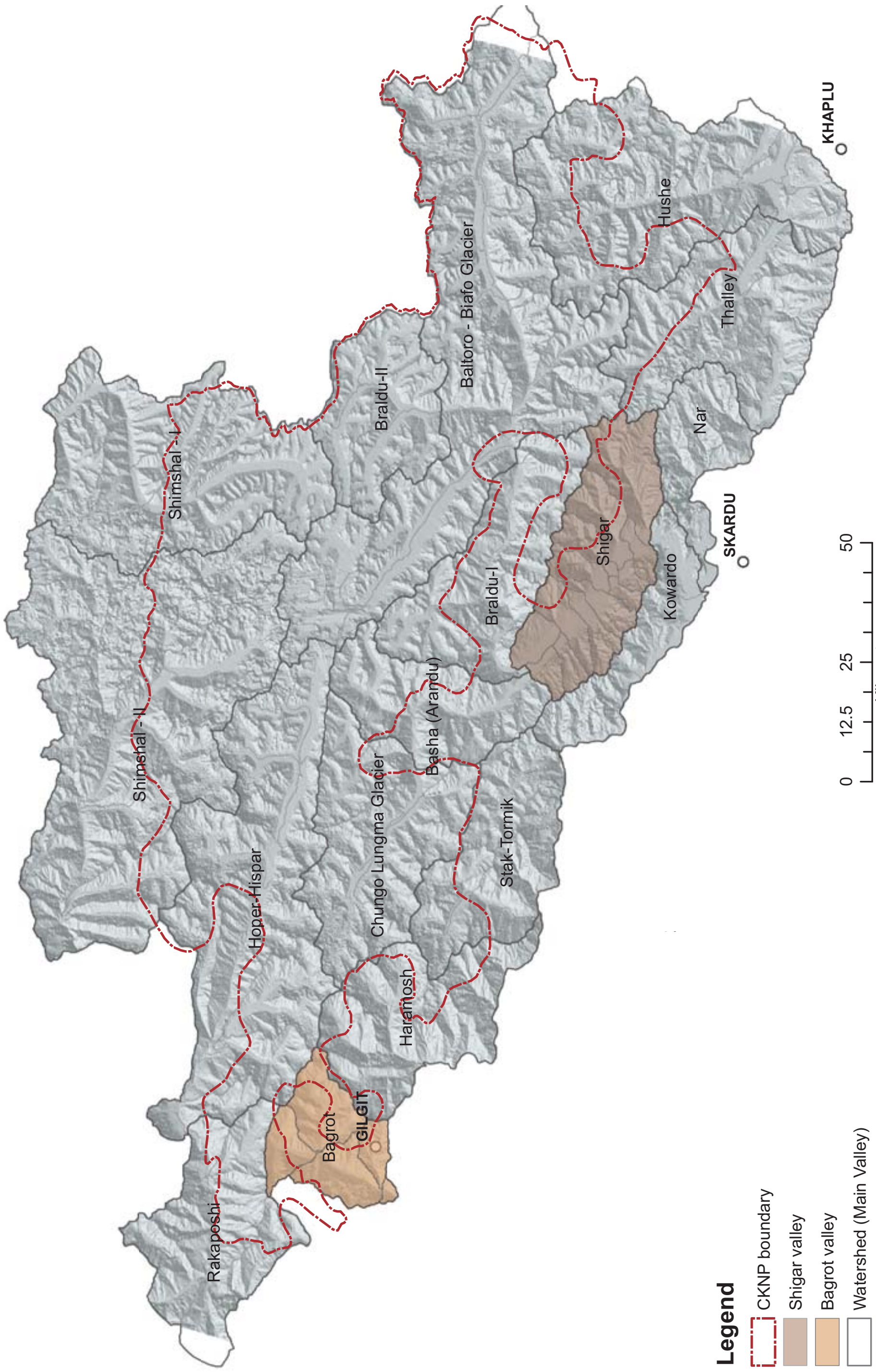


Figure 4.9: Map showing Bagrot and Shigar valleys along with existing PA boundary

Table 4.7: Satellite datasets specifications

Study Area	Satellite Image	Date	Resolution	**No. of Bands**
Bagrot	Multispectral	27 Sep, 2008	10 m	4
Bagrot	Panchromatic	27 Sep, 2008	2.5 m	1
Shighar	Multispectral	17 Oct, 2008	10 m	4
Shighar	Panchromatic	17 Oct, 2008	2.5 m	1

To assign geographic coordinates and to minimize the terrain effect on the geometry of data, images weres ortho-rectified using ERDAS Imagine®.

Study area was truncated on the sub watershed boundary of the Bagrot and Shighar Valleys. Watershed boundary was delineated using 30 m DEM. In order to convert this low contrast image to a high contrast image, standard deviation stretch and brightness contrast control were used for image enhancement. These algorithms enhanced the low contrast of satellite images and made them more interpretable for further processing.

SPOT multi-spectral imagery has lower spatial resolution (10m) and four spectral bands as compared to its panchromatic layer that has higher spatial resolution (2.5m) and a single spectral band. A high-resolution merge was carried out using multiplicative and bilinear interpolation to improve the visual interpretability of the images. The output image is a high-resolution (2.5m) multi-spectral image with improved and greater level of details that was integrated with GIS layers. The high resolution image significantly helped to assign the vegetation classes.

Additional field data collection and legend refinement

In the initial land cover derived from ASTER satellite images, particularly Bagrot Valley was found very diverse in terms of its vegetation cover. Because of this diversity an additional field survey was carried out to collect the sample data from all the strata of vegetation. The survey was conducted during the period of 23 June to 2 July 2009, using LCCS data encoding forms and GPS receivers. A total of 8 different field investigation trips were made. A total of 28 sample plots (100 x 100m) and 60 GPS-linked observation points with 200 photographs from all locations were taken. A2 sized field maps were prepared using False Colour Composites (FCC) of band 3 2 1 RGB of SPOT satellite data at 1:35,000 and 1:25,000 scales, with geographic grid of one minute intervals for use during the survey. Based on the field survey and details available on satellite images, the LCCS legend was further refined and extended as given in Table 4.8.

Table 4.8: Refined LCCS legend for valley level land cover classification

LCCCode, LCCLevel	LCCOwnLabel	LCCLabel	Own Label
21499-121340, A3A20B2XXD2E1-A21	Needleleaved Evergreen Forest	Needle leaved Evergreen Closed to Open (100-40)% Trees	Conifers (Spruce/ Blue pine)
21497-121340, A3A20B2XXD1E2-A21	Broadleaved Forest	Broadleaved Deciduous Closed to Open (100-40)% Trees	Birch
20155, A4A10B3XXD2E1	Needleleaved Shrubs	Needleleaved Evergreen Thicket	Junipers
21124, A4A11B3XXD2 E1F2F6F10G3	Needleleaved Shrubs mixed with Dwarf Shrubs	Needleleaved Evergreen Shrubland with Shrub Emergents	Junipers mix with shrubs
20022-12050, A4A11B3-B10	Dwarf Shrubs	Open Dwarf Shrubs (Shrubland)	Small Shrubs
20056-12050 A4A14B3-10	Sparse Dwarf Shrubs	Sparse Dwarf Shrubs	Sparse Dwarf Shrubs
20056-12050-L3L9, A4A14B3-B10-L3L9	Sparce shrubs on scree	Sparse Dwarf Shrubs Major Landclass: Steep Land, Slope Class: Steeply Dissected To Mountainous	Landslide area with shrubs
20174-4439, A4A11B3XXD1E2-A13B9	Broadleaved Medium to High Shrubs	Broadleaved Deciduous (40 - (20-10)%) Medium High Shrubland	Shrubs
21462-121340, A6A20B4-A21	Grassland	Closed to Open (100-40)% Grassland	Grasses
42347 A2A20B4C1	Grasses on Flooded area	Closed to Open Herbaceous Vegetation On Permanently Flooded Land	Grasses on Flooded area
41971-33699 A4A20B3C1XXXX F2F4F7G4-B10G12	Shrub/Grasses on Flooded area	Closed to Open Dwarf Shrubs With Short Herbaceous Vegetation On Permanently Flooded Land	Shrub mix with Grasses on Flooded area
10001-1891-W7, A1-A7A10-W7	Broadleaved Plantation	Broadleaved Deciduous Tree Crop(s) Crop Cover: Plantation(s)	Plantation
10025 A3	Cultivated Area	Herbaceous Crop(s)	Agriculture
5003, A4	Settlements	Non-Linear Built Up Area(s)	Settlements

6002-9, A3-A15	Stones near water	Bare Rock And/Or Coarse Fragments - Stones	Stones/ Boulders
8007-72 A2B2-B4B8	Snow Debris	Seasonal Snow (Surface Aspect: Bare Rock) (Snow presence 6-4 months)	Snow Debris
6002-1 A3-A7	Bare Rock	Bare Rock(s)	Rocks
6006 A6	Sand	Loose And Shifting Sands	Soil
8003-19 A1B2-B6	Mud Soil	Non-Perennial Natural Waterbodies (Surface Aspect: Sand)	Mud Flats
8001-1 A1-A4	Water	Natural Waterbodies (Flowing)	Water
8008-9 A3-A6	Glacier	Ice (Moving)	Glacier
8006 A2B1	Snow	Perennial Snow	Snow

Satellite image interpretation

Multi-scale object-based image analysis was performed to develop the land cover map of Bagrot Valley. A hierarchical network, with three levels of image objects was created. Segmentation of the image data at fine and coarse scales is important in the object-based multi-scale analysis in order to extract boundaries of the dominant objects occurring at the corresponding scales (Mallinis et al. 2008). During the study image segmentation with various combinations of parameters (scale, shape and compactness) was performed and analyzed (Table 4.9). After a number of trials, three different scales (200, 100 and 40) were determined by visual inspection of segmentation results to construct image segmentation hierarchy. Once appropriate scale factors were identified, the colour and shape criterion were modified to refine the shape of the image objects. Most published works have found that more meaningful objects are extracted with higher weight for colour criterion (Mathieu et al. 2007).

Table 4.9: Parameters used for segmentation hierarchy

No.	Level	Scale Parameter	Shape	Colour	Smoothness	Compactness
01	L1	40	0.10	0.90	0.5	0.5
02	L2	100	0.15	0.85	0.5	0.5
03	L3	200	0.20	0.80	0.5	0.5

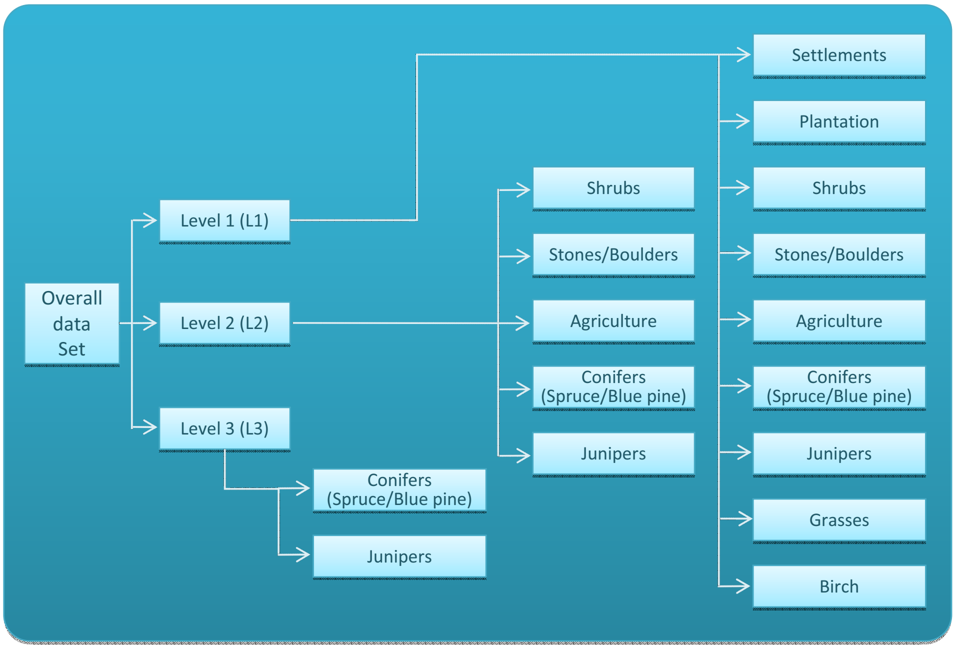


Figure 4.10: Optimal tree for classification categories

The layers chosen for the segmentation of the three regional levels were empirically based on visual inspection of results. The first (lowest, L1) of the three different level of segmentation was introduced to depict small patches with similar land cover type (e.g. blue pine, spruce, birch, settlements and agricultural fields). Whereas the other land cover classes such 'snow and water' and 'glaciers, rocks and dwarf shrub lands' were delineated at coarser and medium levels (L3 and L2) of image object hierarchy, respectively (Figure 4.10). Apart from defining a category for each land cover class, it was necessary to define categories that correspond to patches presenting a mixture of needleaved species with grasses and shrub. During the field survey, it was observed that in some areas it was not possible to discriminate groups or patches of pure species composition. Conifer tends to occupy higher altitudes and north facing slopes, but they also occur at southern slopes and lower altitudes usually mixed with deciduous/ shrubs and grasses.

During the classification process, it was observed that some objects characterized by 'water' at level three of classification were wrongly classified as objects of 'rocks (shadowed) and juniper (shadowed)'. Similarly, some of segments comprising 'fallow agricultural fields (ploughed)' were classified as 'soil'. However, DEM and rules of image object hierarchy were incorporated to restrict the mixing of classes at particular level of hierarchy. Great spectral variability was found in reflectance of objects comprising 'settlements and regularly flooded areas', and the automated classification task for these classes become more difficult. Most of the times these objects remained unclassified and they were manually modified and interpreted.

Results and discussion

Figure 4.11 and 4.12 show the classification results of Bagrot and Shigar Valley and Table 4.10 and 4.11 describe the area of each land cover classes.

In Bagrot Valley, steppe like vegetation dominates below 2200m. Above this altitude the major agricultural and plantation areas stretch up to 2300m. However, small patches can be seen even up to 2800m. Major tree species including, *Pinus wallichiana*, *Picea smithiana*, *Juniperus* and *Betula utilis* are spread between 2800m and 4000m. Higher regions are dominated by the alpine meadows until the rock and ice zone is reached. There are several glaciers situated within the drainage basin of Bagrot Valley, namely Hinarche, Burche, Gutumi, Yune, Diran, Beufar, Salini, Aguzapi, Shidelli, Garroy and Palloy.

In Shigar Valley, major vegetation classes include *Juniperus* spp. Dwarf Shrubland, Grassland, Plantation and Agriculture Fields whereas major non vegetative cover classes are Bare Rocks, Ice, Scree, Soil and Water. Agriculture Fields and Plantation are found below the elevation of 2500m. Dwarf Shrubs range from 2500 to 4000m and it covers about 20% of total area of the valley. *Juniper spp*. is mostly found on the northern aspect at elevations from 3500m to 4500m. Mostly grasses are present above the elevation of 4500m up to the snow line.

Table 4.10: Area distribution of land cover classes of Bagrot Valley

Sr. No.	LCCS label	Own label	Area (ha)	% Area Cover
1	Needle leaved Evergreen Closed to Open (100-40)% Trees	Conifers (Spruce/Blue pine)	1,468	3.36
2	Broadleaved Deciduous Closed to Open (100-40)% Trees	Birch	244	0.56
3	Needleleaved Evergreen Thicket	Junipers	2,334	5.34
4	Needleleaved Evergreen Shrubland with Shrub Emergents	Junipers mix with shrubs	3,137	7.17
5	Open Dwarf Shrubs (Shrubland)	Small Shrubs	4,961	11.34
6	Sparse Dwarf Shrubs Major Landclass: Steep Land, Slope Class: Steeply Dissected To Mountainous	Landslide area with shrubs	1,677	3.84
7	Broadleaved Deciduous (40 - (20-10)%) Medium High Shrubland	Shrubs	70	0.16
8	Closed to Open (100-40)% Grassland	Grasses	2,653	6.07
9	Broadleaved Deciduous Tree Crop(s) Crop Cover: Plantation(s)	Plantation	386	0.88
10	Herbaceous Crop(s)	Agriculture	587	1.34
11	Non-Linear Built Up Area(s)	Settlements	29	0.07
12	Bare Rock And/or Coarse Fragments - Stones	Stones/Boulders	88	0.20
13	Bare Rock(s)	Rocks	491	1.12
14	Natural Waterbodies (Flowing)	Water	142	0.33
15	Ice (Moving)	Glacier	1,385	3.17
16	Perennial Snow	Snow	23,330	53.35
17		Cloud	745	1.71
Total Area			43,733	100

Table 4.11: Area distribution of land cover classes of Shigar Valley

Sr. No.	LCCS label	Own label	Area (ha)	% Area Cover
1	Needleleaved Evergreen Thicket	Juniper Spp.	1,530	1.74
2	Needleleaved Evergreen Shrubland with Shrub Emergents	Juniper Spp. Mixed with Dwarf Shrubs	1,892	2.15
3	Open Dwarf Shrubs (Shrubland)	Open Dwarf Shrubs	13,066	14.87
4	Sparse Dwarf Shrubs	Sparse Dwarf Shrubs	4,540	5.17
5	Closed to Open (100-40)% Grassland	Grasses	8,056	9.17
6	Closed to Open Herbaceous Vegetation On Permanently Flooded Land	Grasses on Flooded area	444	0.51
7	Closed to Open Dwarf Shrubs With Short Herbaceous Vegetation On Permanently Flooded Land	Grasses/Shrubs on Flooded area	299	0.34
8	Herbaceous Crop(s)	Cultivated Area	2,427	2.76
9	Broadleaved Deciduous Tree Crop(s) Crop Cover: Plantation(s)	Plantations	3,090	3.52
10	Bare Rock(s)	Bare Rocks	21,158	24.08
11	Seasonal Snow (Surface Aspect: Bare Rock) (Snow presence 6-4 months)	Snow Debris	1,680	1.91
12	Sparse Dwarf Shrubs Major Landclass: Steep Land, Slope Class: Steeply Dissected To Mountainous	Scree	3,082	3.51
13	Loose And Shifting Sands	Soil (Sand)	3,161	3.60
14	Non-Perennial Natural Waterbodies (Surface Aspect: Sand)	Mud Soil	1,236	1.41
15	Non-Linear Built Up Area(s)	Settlements	5	0.01
16	Natural Waterbodies (Flowing)	Water	1,195	1.36
17	Ice (Moving)	Snow	20,395	23.22
18	Perennial Snow	Moraine/Glacier	584	0.67
Total Area			87,848	100

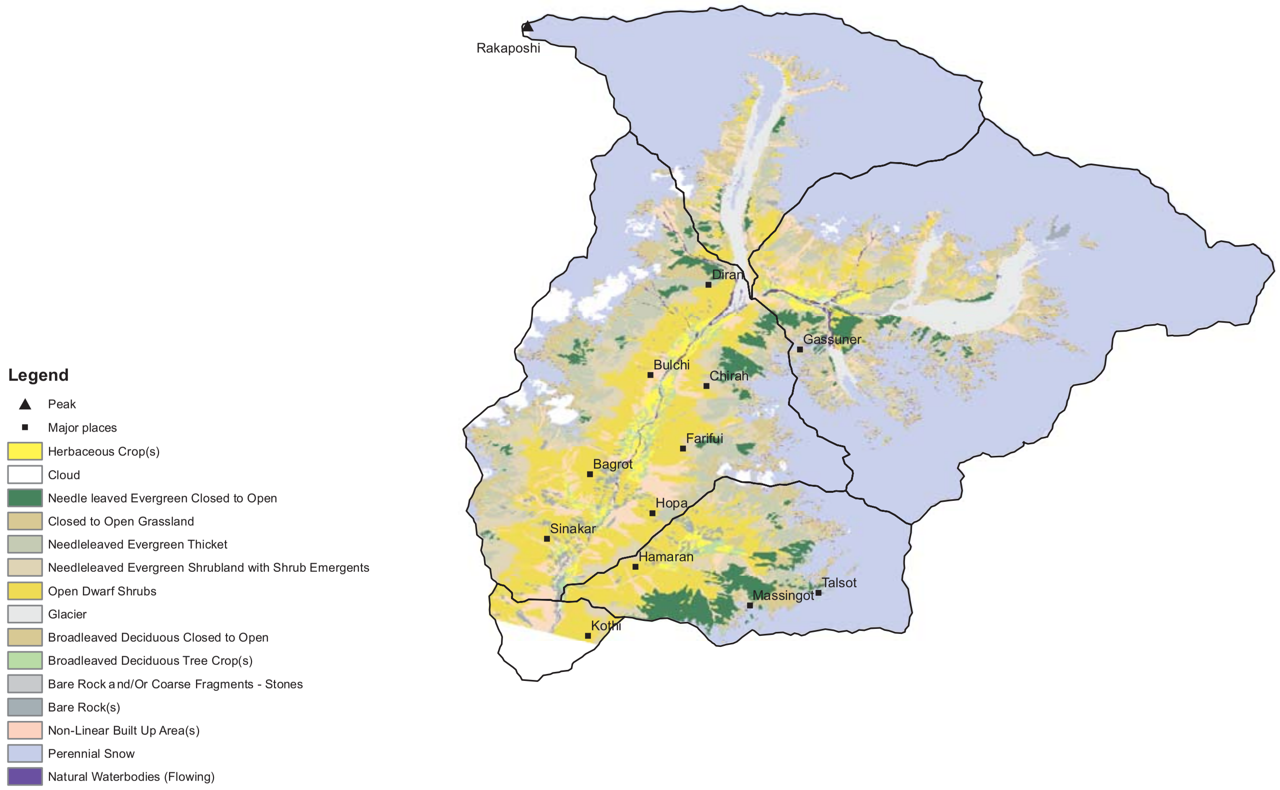


Figure 4.11: Land cover map of Bagrot Valley

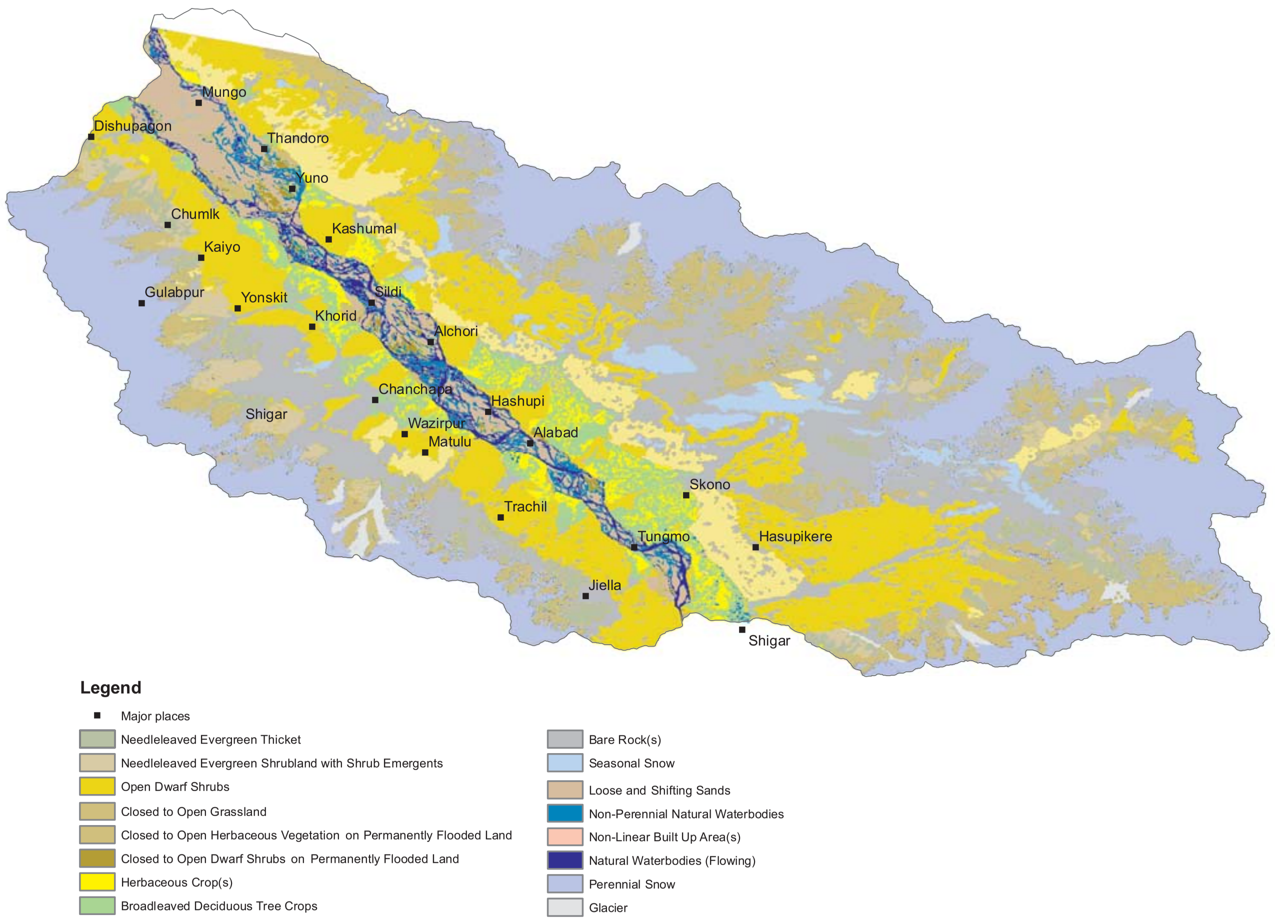


Figure 4.12: Land cover map of Shigar Valley

The physical topographic factors, particularly elevation and aspect, are part of the major governing factors for distribution of different vegetation types. The distributions of land cover features against elevation and aspect were analyzed. These are represented through trend lines based on 50 point moving average.

Distribution of vegetation along elevation in Bagrot valley: Figure 4.13 shows the graphical representation of elevation versus areas of different vegetation classes of Bagrot Valley. The elevation was derived from the DEM and the areas of vegetation cover were derived from the digital image classification of September 2008 SPOT-5 satellite data. Eight vegetation cover classes shown in the graph are representing the trend with increasing elevation.

Distribution vegetation along aspect: Figure 4.14 is a polar graph of aspect versus area in sq m of different land/vegetation cover classes, derived from the digital image classification of September 2008 SPOT-5 satellite data. The polar graph displays data in terms of the radial position versus the angular values.

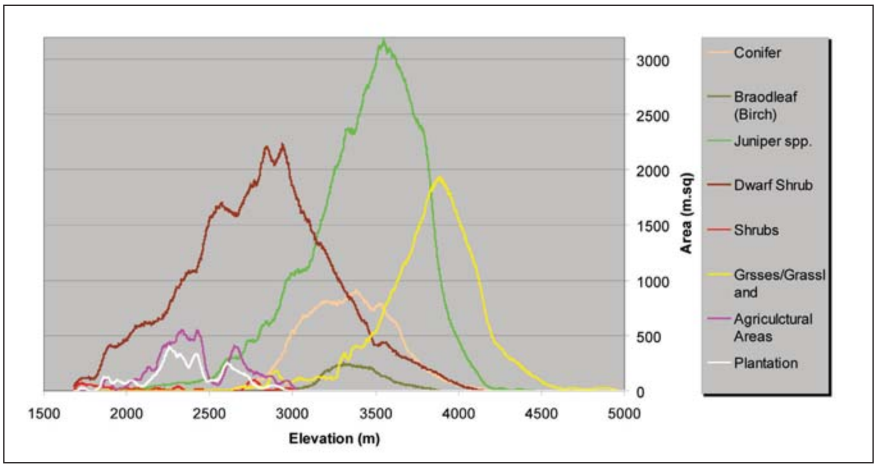


Figure 4.13: Line graph on distribution of vegetation along elevation in Bagrot Valley

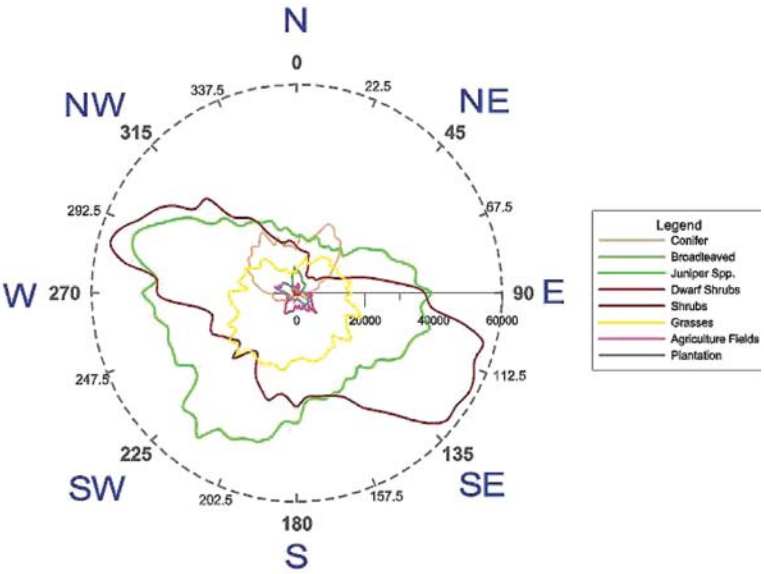


Figure 4.14: Polar graph on distribution of vegetation along aspect

Figure 4.15: Spruce forest near Talsot village and its illegal cutting

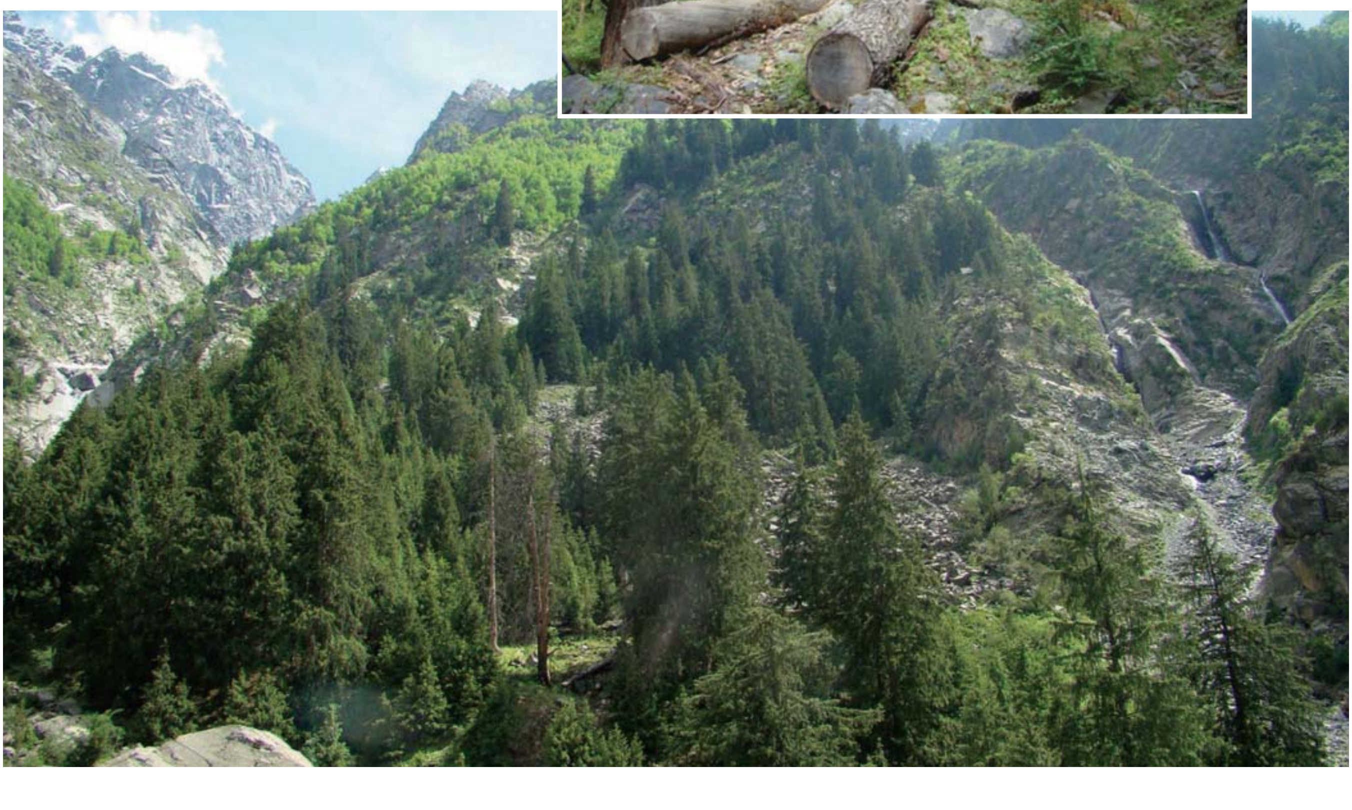


Figure 4.16: Blue pine forest near village Gassuner

According to Schickhoff (2005), in the valleys of Bagrot, Naltar, Chaprot and on the Rakaposhi North Slope (Nilt, Minapin), upper timberline develops between 3700m and 3800m in north aspects, made up by *Betula utilis* (Birch) and *salix karelinii*, whereas south-facing slopes have upper most *Juniperous turkestanica* trees between 3800m and 4000m. These observations can be clearly verified through the distribution graphs given above. The elevation range of *Juniperous spp*. in southern aspect is spread up to 4200m in Bagrot Valley.

Within the Bagrot Valley, relatively large patches of *Spruce* and *Juniper* are found in the south-eastern part near Talsot Village. However, the forest is under extreme anthropogenic pressure and recent cutting of trees were also observed during the field survey (Figure 4.15)

A few small patches of *Pinus wallichiana* were observed in the north-eastern part near the village of Gassuner (Figure 4.16) and rest of the Conifer Forest consisted of Spruce. According to the local people, all these trees were recent regeneration.

Distribution of vegetation along elevation in Shigar Valley: Figure 4.17 shows the graphical representation of elevation versus areas of different vegetation classes of Shigar Valley. DEM and digital image classification of October 2008 SPOT-5 satellite data were used to derive elevation and five different vegetation cover classes respectively. The trend of vegetation cover classes with increasing elevation are shown in the graph.

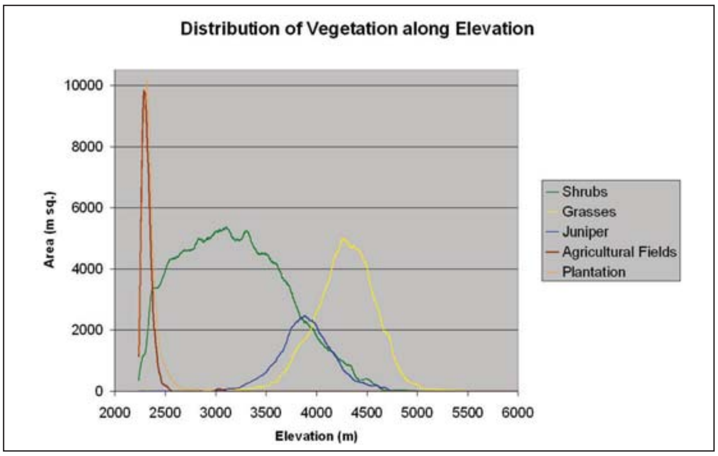


Figure 4.17: Line graph of Vegetation distribution along elevation in Shigar Valley

Distribution vegetation along aspect: Figure 4.18 is a polar graph of aspect versus area in sq m of different land/vegetation cover classes, derived from the digital image classification of October 2008 SPOT-5 satellite data. The polar graph displays data in terms of the radial position versus the angular values.

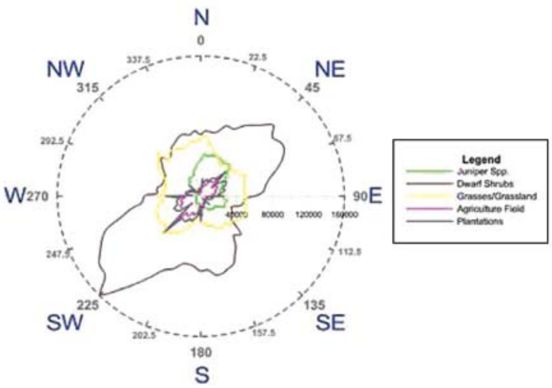


Figure 4.18: Polar graph on distribution of vegetation along aspect in Shigar valley

Major vegetation classes of Shigar Valley include *Juniperus* spp. Dwarf Shrubland, Grassland, Plantations and Agriculture Fields. Dwarf Shrubs range from 2500m to 4000m and it covers about 20% of total area of the valley. *Juniperus spp*. is mostly found on the northern aspect at elevation ranges from 3500m to 4500m. Mostly grasses are present above the elevation of 4500m up to the snow line.


Laxmi Krishna Amatya

5

Land Cover Mapping in Qomolangma National Nature Preserve (QNNP)

Study area

The QNNP is located close to the border with Nepal, including Tingri, Gyirong, Nyalam and Dinggye Counties in the Tibet Autonomous Region of China (Figure 5.1). The reserve extends from national boundaries to the south, the Yar-lung Zangbo River and south Tibet watershed to the north, the watershed between the Ming-jiu River and Yala River to the east and watershed of Baruo Zangbo, Amuga River and Sangzhuo River to the west. The area of the reserve is about 34,000 sq km, lying in a range from 27°48´N to 29°19´N and from 84°28´E to 88°23´E (Zhang et al. 2007).

Climate

The complex ecosystems of QNNP stretch across the northern slopes of the Himalaya. Five valleys cut through the Himalayan chain letting warm air currents and monsoon rains northward from the Indian Ocean into the edge of the arid Tibetan Plateau. At the valley bottoms, the climate is subtropical. With the rise in elevations the climate ranges from warm temperate, subalpine cold temperate, alpine sub-frigid to alpine frigid climates. In northern QNNP, the south Tibetan plateau climate is cold and dry, which is the typical characteristic of the plateau continental climate (Li 1993, Cidan 1997). According to the analysis of meteorological data of Tingri and Nyalam, the 30-year average annual air temperature is 2.87°C in Tingri and 3.61°C in Nyalam from 1971 to 2000 (Yang et al. 2006). The 30-year-averaged annual precipitation is 259.81 mm in Tingri and 665.57 mm in Nyalam.

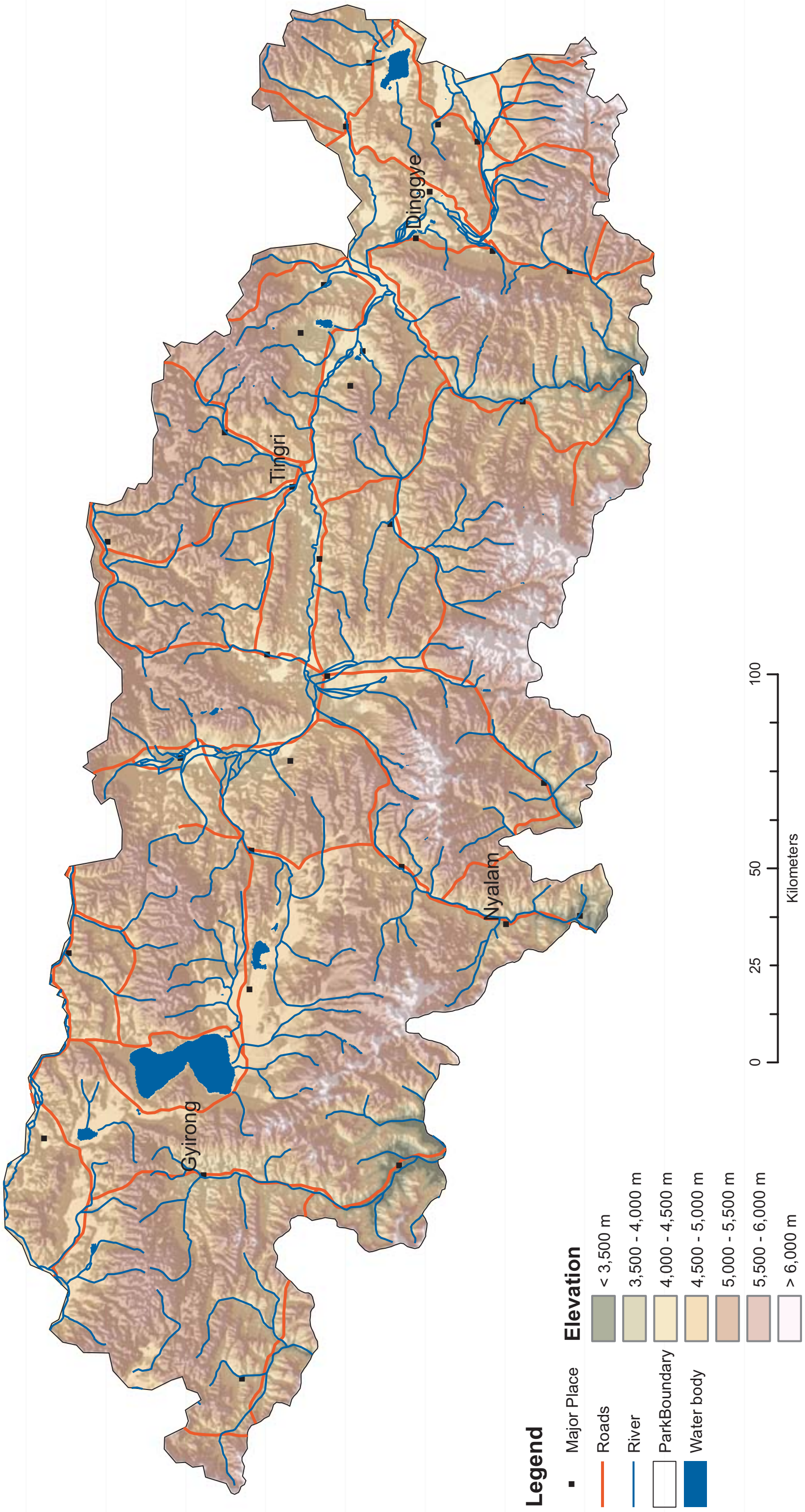


Figure 5.1: Map of QNNP

Ecology

QNNP has an abundance of ecosystem types and its vertical zones are remarkable. The vertical range of vegetation distribution is from 1600m (on the southeastern slope and the southwestern slope) to 6000m/ 6200m (Jiang 1974, Team of Scientific Expedition to Tibet of CAS 1975, Fei 1981, The Comprehensive Scientific Expedition to the Qing-hai-Xizang Plateau 1988). From the foot to the peak, the vertical vegetation zones on the south slope of the Himalayas are composed of the mountain subtropical evergreen broad-leaved forests, mountain warm-temperate needle-leaved and broad-leaved mixed forests, mountain cold-temperate needle-leaved forests, subalpine cold-temperate needle-leaved forests, subalpine frigid shrubs and meadows, alpine frigid meadows and cushion vegetation and alpine frigid moraine lichens. Above 5500m is the snow and ice belt. From the foot to the peak, the vertical vegetation zones on the north slope of the Himalayas consist of plateau frigid semi-arid steppes, alpine frigid meadows and cushion vegetation and alpine frigid moraine lichens.

Geomorphology

The QNNP is composed of two big geomorphic units – the Himalayan highlands and the Xizang plateau. The former has towering snowy peaks and deep river valleys, and those elevations are different by thousands of meters. Between towering snowy peaks and deep river valleys contain abundant morphostructure, fluvial landforms, glacial landform and peri-glacial landform. In the latter unit, topographic fluctuation is slower, including broad valleys and intensive lakes, which show the main characters of plateau geomorphology (Li 1993).

Soil

The QNNP has unique hydrothermal condition, which produces complex soil vertical distribution. By dividing Himalayas, from bottom to top, the northern side mainly contains subalpine steppe soil, alpine meadow soil and alpine meadow-steppe soil, original alpine meadow soil and alpine frigid desert soil. The southern side mainly contains alpine yellow brown earth, alpine acidic brown earth, alpine brown soil, subalpine meadow soil, alpine meadow soil (including original alpine meadow soil) and alpine frigid desert soil (Team of Scientific Expedition to Tibet of CAS 1975).

Economy

The four counties in the QNNP are all agricultural counties with a population of about 96,000 in 2007. According to economic statistics in 2007, the total gross output value of farming, forestry and animal husbandry was approximately 284.43 million Yuan, which included 149.9 million Yuan of output value of farming, 11.14 million Yuan of forestry and 123.39 million Yuan of animal husbandry. At the end of 2007, the amount of livestock on hand was 937.7,000 (Tibet Bureau of Statistics 2008).

Previous land cover mapping initiatives

Scientific research in QNNP has been mainly carried out through four previous comprehensive scientific expeditions of systematic and multidisciplinary fields referring to ice core, glacier, atmospheric physics and chemistry, ecology, hydrology, as well as responding to the global environmental change. These research expeditions were carried out in 1959-1960, 1966-1968, 1975, and 2005, respectively, and organized by first-class academic institutions in China, with the Chinese Academy of Sciences (CAS) playing a leading role in the expeditions.

Many thematic materials and maps on land cover in QNNP were completed based on the comprehensive scientific expeditions, such as land-use map of Xigaze, grassland type map of Xigaze, vegetation map of Tibet Autonomous Region of China, topographic maps and so on, that can be used as well as the ancillary data for the latest land cover mapping in QNNP. With the development of remote sensing (RS) and GIS, the national land-use and land cover mapping based on RS and GIS have been completed by Institute of Geographic Sciences and Natural Resources Research (IGSNRR) which covered from late 1980s to around 2000.

Legend definition

The land cover classification system at QNNP has been built based on the FAO/UNEP LCCS and many reference data on land cover types and distributions from past studies. The following classes were preliminarily identified for the land cover mapping (Table 5.1).

Table 5.1: LCCS legend for QNNP

LCCCode	LCCLevel	LCCOwnLabel	LCCLabel
6005	A5	Bare Soil	Bare Soil and/or Other Unconsolidated Material(s)
6002-1	A3-A7	Bare Rock	Bare Rock(s)
6002-2	A3-A8	Gravels, Stones and Boulders	Gravels, Stones and/or Boulders
5001	A1	Built Up Area	Built Up Area(s)
10025-S1	A3-S1	Cultivated Area	Herbaceous Crop(s) Crop Type: Food Crops
8001-1	A1-A4	River	Natural Waterbodies (Flowing)
8001-5	A1-A5	Lake	Natural Waterbodies (Standing)
8005	A2	Snow	Snow
8008-9	A3-A6	Glacier	Ice (Moving)
20062-12293	A5A14B4-B13	Alpine Sparse Vegetation	Sparse Short Forbs
20205	A5A11B4XXE5	Forbs	Open Forbs
21462	A6A20B4	Closed to Open Grassland	Closed to Open Grassland
20034	A6A10B4	Closed Grassland	Closed Grassland
42347-4741	A2A20B4C1-B13	Closed to Open Flooded Herbaceous	Closed to Open Short Herbaceous Vegetation On Permanently Flooded Land
20152	A4A10B3XXD1E1	Broadleaved Evergreen Closed Shrub land	Broadleaved Evergreen Thicket
20174	A4A11B3XXD1E2	Broadleaved Deciduous Open Shrub land	Broadleaved Deciduous Shrub land
20176	A4A11B3XXD2E1	Needle-leaved Evergreen Open Shrub land	Needle-leaved Evergreen Shrub land
20089	A3A10B2XXD1E1	Broadleaved Evergreen Closed Forest	Broadleaved Evergreen Trees
20090	A3A10B2XXD1E2	Broadleaved Deciduous Closed Forest	Broadleaved Deciduous Trees
20611-13175	A3A10B2XXD2E1F2 F5F7G2-B5E3G5	Mixed Forest	Multi-Layered Mixed High Trees (With Second Layer Of High Trees)
20132	A3A11B2XXD1E2	Broadleaved Deciduous Closed to Open Forest	Broadleaved Deciduous Woodland
20134	A3A11B2XXD2E1	Needle-leaved Evergreen Closed to Open Forest	Needle-leaved Evergreen Woodland

Field examples of land cover classes

Built Up Area

Cultivated Area

Bare Rock

Gravels, Stones and Boulders

Bare Soil

River

Snow

Glacier


Lake


Alpine Sparse Vegetation


Closed to Open Grassland


Forbs


Closed Grassland


Closed to Open Flooded Herbaceous


Needle-leaved Evergreen Open Shrub land


Broadleaved Deciduous Open Shrub land

Broadleaved Evergreen Closed Shrub land

Broadleaved Deciduous Closed to Open Forest

Needle-leaved Evergreen Closed to Open Forest

Broadleaved Evergreen Closed Forest

Broadleaved Deciduous Closed Forest

Mixed Forest

Figure 5.2: Examples of land cover classes from the field

Reference data collection

Non-field reference data

Reference data is necessary to gain the land cover map as efficiently and exactly as possible. Land use map of Xigaze, grassland type map of Xigaze, vegetation map of Tibet Autonomous Region of China, books and materials of scientific expeditions (e.g., Tibetan forest, Tibetan vegetation) topographic maps at scale of 1:100 000, etc.) have been collected for training sample. Main distributions of vegetation types were collected as follows:

a) Mountainous Sub-tropical evergreen woodland, broadleaved deciduous and needleleaved evergreen forest (<2600m): *Castanopis hystrix, Machilus yunanenis, Lithocarpus arcaula, Cyclobalanopis xizangensis, Cyclobalanopsis oxyodon, Pinus griffithii*
b) Mountainous warm and wet needleleaved evergreen and hard, broadleaved forest (2400-3300m): *Tsuga dumosa, Abies spectabilis, Pinus roxburghii, Pinus griffithii, Quercus semecarpifolia*
c) Sub-alpine cool temperature needleleaved evergreen and deciduous broadleaved forest (3100-3900m): *Abies spectabilis, Betula utilis*
d) Sub-frigid zone shrubland (3700-4700m): *Rhododendron campanulatum, Rhododendron nivale, Potentilla parvifolia, Caragana tibetica, Caragana versicolor, Sabina pingii var. Wilsonii, Sabina squamata, Hippophae rhamnoides, Hippophae thibetana*
e) Sub-frigid zone grassland (3700-5000m): *Stipa purpurea, Artemisia wellbyi, Artemisia younghusbandii, Orinus thoroldii*
f) Sub-frigid zone meadow (4000-5600m): *Kobresia pygmaea, Kobresia prainii*, *Kobresia cercostachys, Carex montis-everestii, Carex moorcroftii*
g) Frigid zone alpine sparse vegetation (5000-5700m): *Androsace tapete, Arenaria edgeworthiana, Oxytropis tatarica*

To match in the unique coordination system, all the referenced data was scanned with high quality 300 dpi. There are about 50 topographic maps at the scale of 1:100,000 used in QNNP for geo-rectification of remote sensing images, which have been geo-referenced precisely with RMSE of less than 1 m.

Field reference data

A field mission to QNNP was carried out between 3 October and 2 November 2008 to collect samples (about 50 sample plots and 488 observation points) for image interpretation and the validation of the land cover classification as well as to refine the legend.

Before implementing the field survey, the survey routes were planned, investigation sheets were made and important equipments such as GPS, cameras and so on, were prepared. The field job was done by one work team at QNNP directed by one senior biology researcher who has been working at QNNP since the 1970s. The data collection focused mainly on vegetation cover types. Photos were taken with GPS-positioning. Sample plots were marked in different land cover types to obtain detailed information (Figure 5.3). The field work was carried out with the help of the staff of administrative bureau of QNNP in each county.

The actual survey route taken differed considerably from the planned route. More places were covered than originally planned; however, some places were not accessible due to snow or lack of a road (Figure 5.4). The actual route of samples almost covering the whole study area can be seen in Figure 5.5.

Figure 5.3: Field survey of sample plot

Figure 5.4: No road ahead due to snow

Field sample data covers elevations from 1800-6000m for LCCS classification including almost all the land cover types. There are about 50 sample plots and hundreds of GPS-linked descriptive data points collected for the purpose of ground-related satellite images and more than 10,000 photographs were taken along the route with GPS location points. Data sheets were used for recording the location's environmental attributes such as major landforms, slope classes, soils, location, both natural and human induced disturbances, vegetation type and so on. Latitude, longitude, altitude, aspect, slope, soils and location were recorded for each site as required by LCCS classification. Vegetation information included percent crown cover, frequency, height, dominant shrub, grasses and ground layer species. Photographs were taken in each plot. Quadrate sites were subjectively selected on the basis of their ability to portray typical and representative land cover phenomena for the particular setting. The locations of the sample plots and observation points are shown in Figure 5.6.

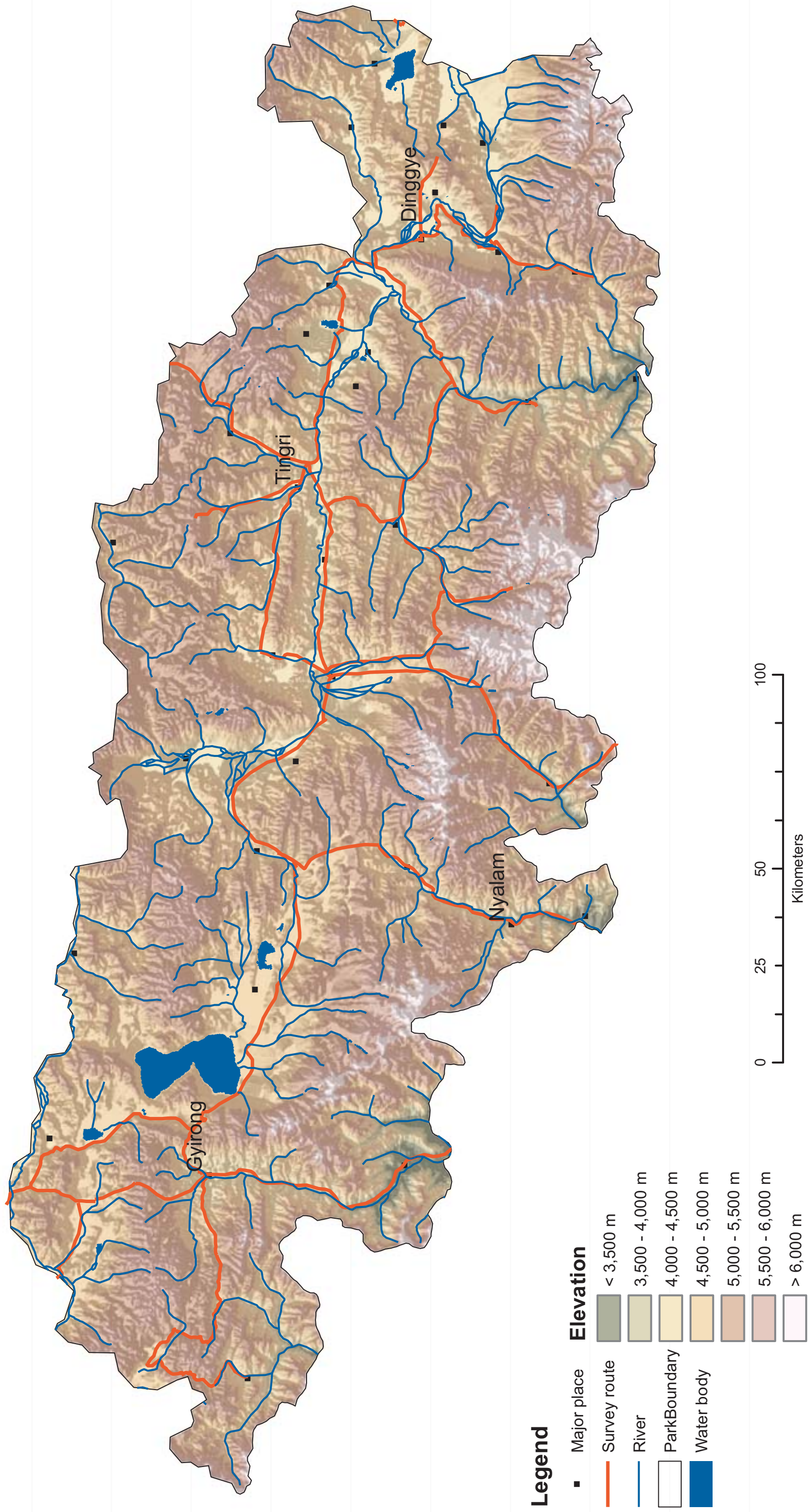


Figure 5.5: Survey route in QNNP

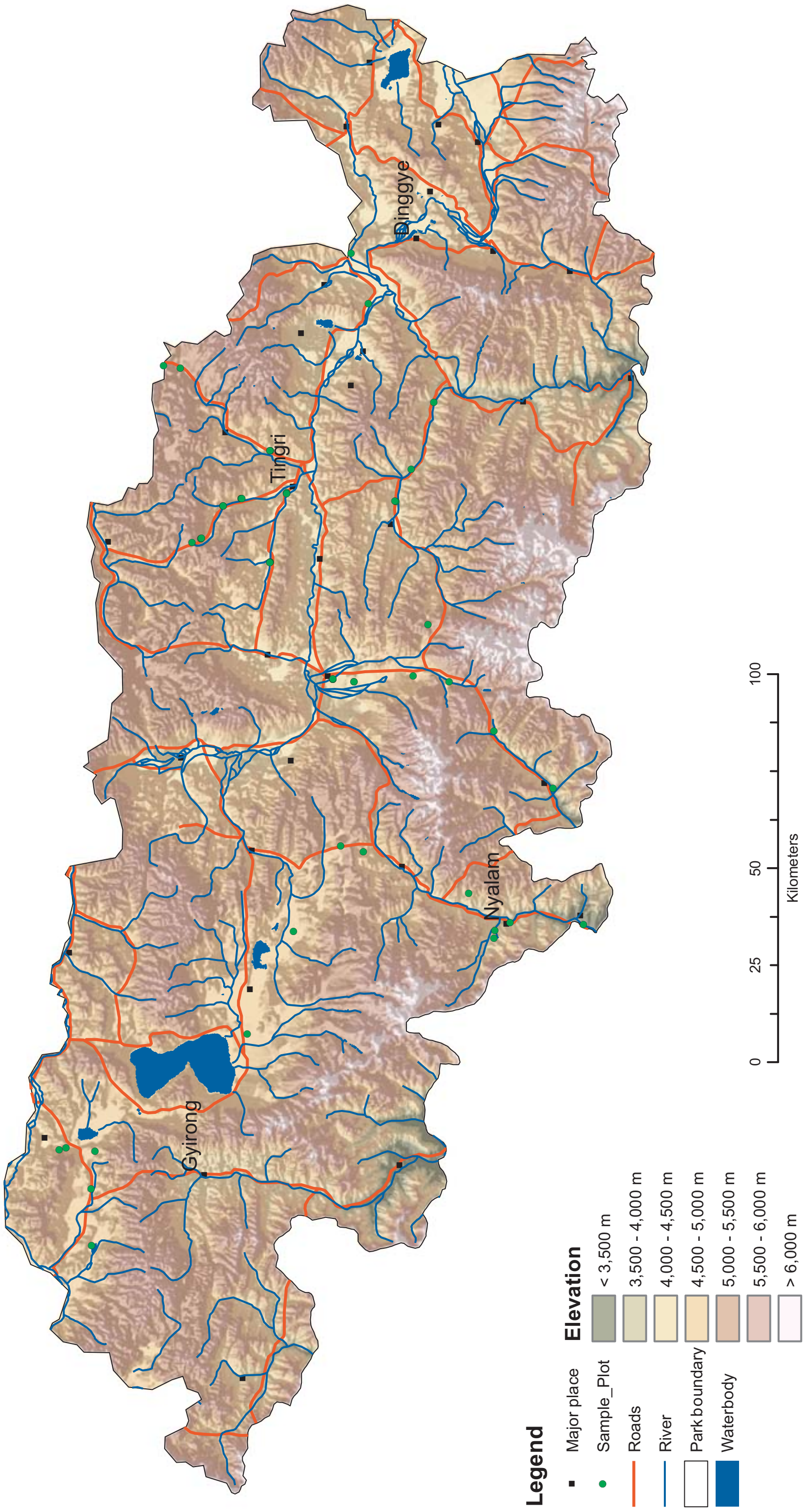


Figure 5.6: Location of sample plots and observation points

Material and methods

Satellite images preparation

For the land cover mapping activities in QNNP, AWiFS and ASTER images were used. AWiFS is a sensor equipped on RESOURCESAT-1 (IRS–P6) with the resolution of 56 m, and its acquired date is 29 March 29, 2007. The main wavebands are as follows:

Band 2 0.52 – 0.59 μm (green)
Band 3 0.62 – 0.68 μm (red)
Band 4 0.77 – 0.86 μm (NIR)
Band 5 1.5 – 1.7 μm (MIR)

The ASTER images were acquired on 23 January, 2006 There are three bands with a resolution of 15 m in the wavelength of NIR with main wavebands listed as follows:

Band 1 0.52-0.60 μm (Green)
Band 2 0.63-0.69 μm (Red)
Band 3 0.76-0.86 μm (NIR)
Band 4 1.60-1.70 μm (SWIR)
Band 5 2.145-2.185 μm (SWIR)
Band 6 2.185-2.225 μm (SWIR)
Band 7 2.235-2.285 μm (SWIR)
Band 8 2.295-2.365 μm (SWIR)
Band 9 2.36-2.43 μm (SWIR)

And there are six bands with a resolution of 30m in the wavelength of SWIR with main wavebands of 1.60-2.43 μm. The images were geo-referenced in the same projection and coordinate system parameters using the rectified topographic maps before using it for land cover data.

The AWiFS image has the advantage of covering a wide area (740 × 740 km) in one frame, and the whole study area can be interpreted by using only one image at the same time to avoid the bias caused by the imageries acquired in different times. The quality of AWiFS was very good for land cover mapping without any cloud in the whole QNNP. Furthermore, only one ASTER image with a higher resolution was selected and used to interpret the area around Mt. Qomolangma (Mt. Everest) to the north of SNPBZ for having a comparable dataset across the border. This can be set up as a good example for better understanding the environment and ecosystem close to the highest elevation and the application of land cover mapping methodology in the HKKH region. To further the study in QNNP, high resolution images such as IKONOS or QUICKBIRD may be considered to be used for land cover investigation at some important sites.

Methodology

The remote sensing software such as Definiens®, ERDAS Imagine® and ENVI® were compared. Several methods were tried using different software for the classification work based on the legend generated. The approach of object-based image analysis was adopted for the land cover classification using the ENVI® software finally. This approach has shown better classification results compared to pixel-based methods as it uses both spectral and spatial information. The following steps were used:

- Defining a minimum mapping unit
- Calculation of key parameters
- Segmentation and merging segments
- Making classification rules and land cover mapping
- Post classification processing

Minimum mapping unit

A minimum mapping unit of 0.6 ha and 8 ha was chosen for ASTER images and AWiFS images (5 × 5 pixels) respectively because this size was easily identifiable in these images.

Calculation of key parameters

By creating a contrast between two bands with very different reflectance characteristics, and using standardized indices based on broadband reflective characteristics, different types of vegetation, soils, river, lake, as well as snow and ice, can be discriminated. Some key parameters such as NDVI, NDSII, and NDWI can help us with land cover classification for differentiating the vegetation/non-vegetation snow/no snow, and water bodies.

Segmentation and merging segments

In ENVI®, segmentation is the process of partitioning an image into segments by grouping neighboring pixels with similar feature values (brightness, texture, color, etc.) These segments ideally correspond to real-world objects. ENVI® employs an edge-based segmentation algorithm that is very fast and only requires one input parameter (scale level). By suppressing weak edges to different levels, the algorithm can yield multi-scale segmentation results from finer to coarser segmentation. A scale parameter of 0-100 is used to determine the maximum heterogeneity for image objects. Modifying the value in the scale parameter varies the size of image objects.

Merging is an optional step used to aggregate small segments within larger, textured areas such as trees, clouds, or fields, where over-segmentation may be a problem. The Merge Level parameter in the ENVI® feature extraction dialog represents the threshold lambda value, which ranges from 0.0 to 100.0. We should ideally choose the highest Merge Level that delineates the boundaries of features as well as possible.

After many trials, the scale parameter of segmentation and merging segments were taken as 40 and 30 for AWiFS, 50 and 60 for ASTER, respectively. The parameters are more controllable and suitable for preview (Figure 5.7 and 5.8).

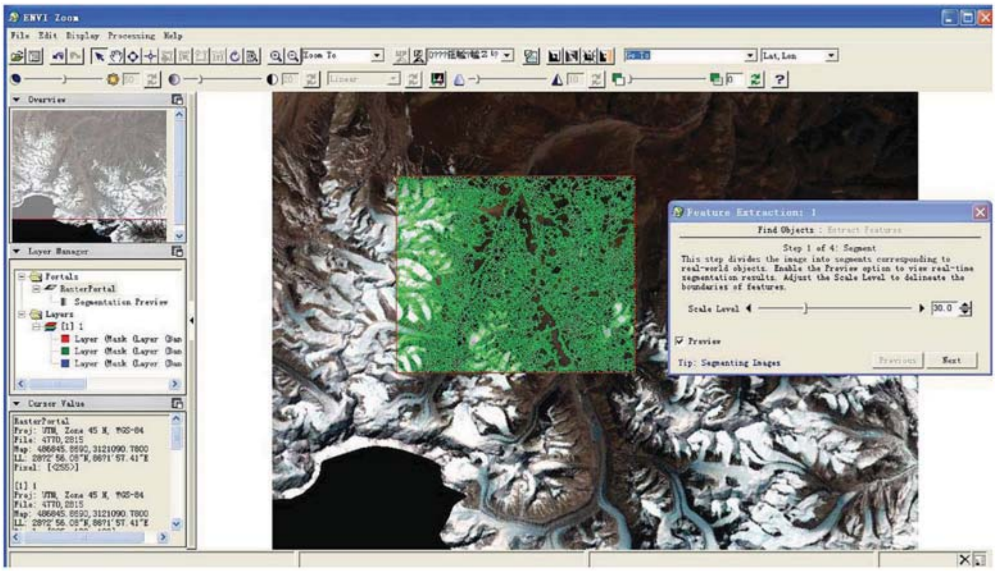


Figure 5.7: Segmentation in the ENVI feature extraction

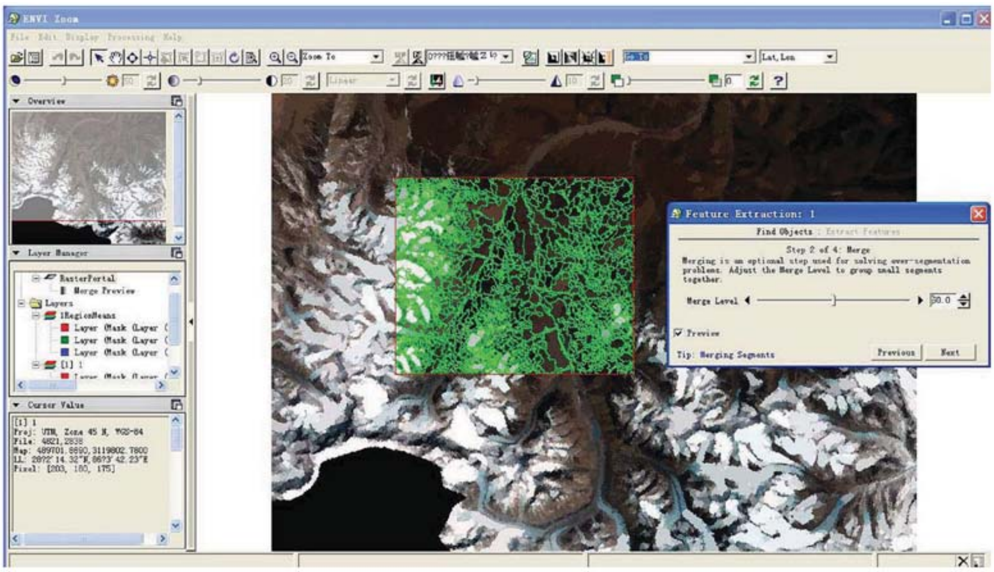


Figure 5.8: Merging segments in the ENVI feature extraction

Making classification rules and land cover mapping.

Classification is the procedure of associating image objects with an appropriate class. A class describes the semantic meaning of image objects in ENVI®. The classes defined in LCCS were defined in ENVI® based on the referenced data and some field samples by the method of rule-based classification (Figure 5.9). Rule-based classification is an advanced method that lets us define features by building rules based on object attributes spatial, spectral, or texture properties of a vector object that can be used to classify the object into a known feature type. Rule-based classification is a powerful tool for feature extraction, often performing better than supervised classification for many feature types (Jin and Paswaters 2007). Rule-building is primarily based on human knowledge and reasoning on specific feature types: for example, vegetation has a high NDVI value.

Class descriptions are created via a fuzzy logic-based system. The standard nearest neighbor classifier was used in the present classification process. Firstly, a lot of statistical analysis of reflectance values of each band for land cover types to identify the typical features was carried out based on the reference data and field survey materials. Secondly, glacier and snow were classified by NDSII effectively, and then, NDWI and visible bands were introduced to further differentiate glacial lake, river and lake. Thirdly, the classification was done separately for vegetated area and non-vegetated area using the NDVI mask. Finally, the sub-classifications of grasslands, scrublands and forests were identified based on the sample points and ecological environmental feature, and image objects were linked to class objects defined in LCCS by classification link objects. Each classification should be labeled as a unique code and land cover mapping can be completed.

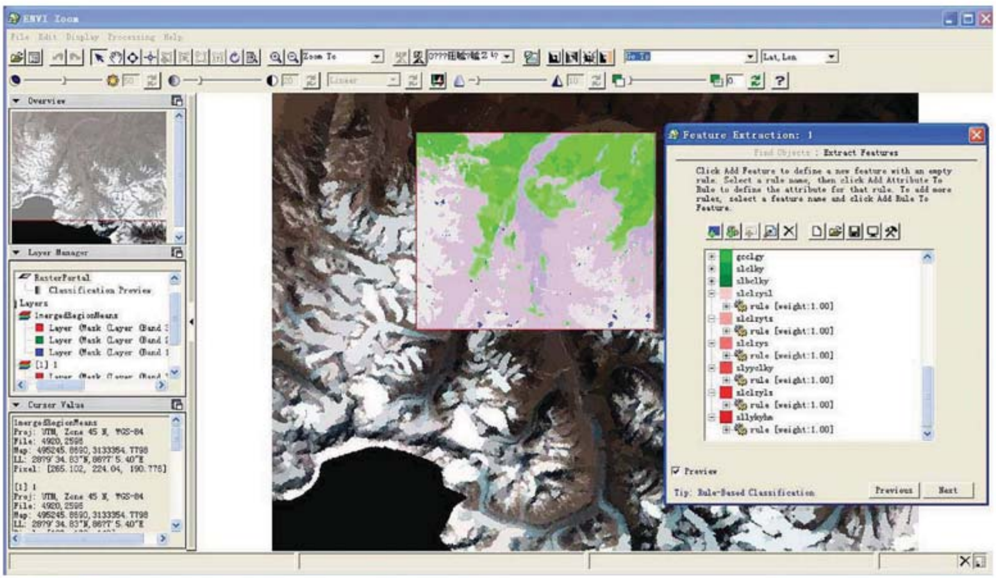


Figure 5.9: Rule based classification

Post classification processing

After the classification, the draft data was exported in the format of shape file, and clipping was used to remove the area beyond the extent of study area, then, the polygons with an area smaller than the defined minimum mapping units were eliminated. The standard codes and labels of LCCS were imported to the classified data, and the topology of data was updated to produce the final land cover map.

Results

According to the methodology of land cover mapping mentioned above, the land cover maps from AWiFS and ASTER images at QNNP were completed (Figure 5.10 and 5.11).

Land cover from AWiFS

The total area of the land cover data derived from AWiFS within the four counties of QNNP is 3,6000 sq km which covers larger than the area of QNNP (3,3000 sq km) in order to keep the consistency for the ecological economic statistics analysis for the next step. The statistical results of each land cover classification (Table 5.2) show the following: 24.69% of the study area which is approximately 9,035 sq km is covered by snow at the acquired time of AWiFS image. Percentages of closed to open grassland, alpine sparse vegetation, forbs and closed grassland are more than 10%, and their areas cover, 6,561 sq km (17.93 %), 6,096 sq km (16.66%), 4,379 sq km (11.97%) and 3, 848 sq km (10.52%) respectively. The total area of shrub land makes about 963 sq km (2.63%), the biggest one of all the shrub lands is needle-leaved evergreen open shrub land. The total area of forest is very limited at QNNP, about 406 sq km with the percentage of not more than 1.2%. Bare area covers about 10.27% with area of 3,757 sq km consisting of bare rock, bare soil and gravels, stones and boulders. There is 383 sq km which is covered by lake. One of the bigger lakes is the well-known Peiku Lake.

The tabulated statistics of land cover type in each elevation zone at interval of 1000 m were completed (Table 5.3). The results show that the areas above 6000 m mainly consist of snow, glacier, gravels, stones and boulders, bare rock and bare soil; vegetation type between 5000m and 6000m are mainly alpine sparse vegetation and closed grassland; lakes are mainly located between 4000m and 5000m; grasslands with closed grassland, closed to open grassland and forbs mainly are distributed between 4000m and 5000 m; Shrub lands mainly are distributed between 3000m and 5000m; the distribution of forest is almost below 4000m; and cultivated area is distributed widely from lower 2000m up to 5000 m.

Table 5.2: Statistics of land cover map derived from AWiFS image

Type	Area (sq km)	Percentage (%)
Lake	383.10	1.05
River	60.75	0.17
Snow	9,035.28	24.69
Glacier	653.21	1.79
Bare Soil	197.07	0.54
Bare Rock	2,730.97	7.46
Gravels, Stones and Boulders	829.19	2.27
Built Up Area	2.00	0.01
Cultivated Area	36.51	0.10
Alpine Sparse Vegetation	6,096.50	16.66
Forbs	4,379.06	11.97
Closed to Open Grassland	6,561.07	17.93
Closed Grassland	3,848.45	10.52
Closed to Open Flooded Herbaceous	410.57	1.12
Broadleaved Evergreen Closed Shrub land	214.90	0.59
Broadleaved Deciduous Open Shrub land	199.24	0.54
Needle-leaved Evergreen Open Shrub land	549.60	1.50
Broadleaved Evergreen Closed Forest	18.33	0.05
Broadleaved Deciduous Closed Forest	14.54	0.04
Mixed Forest	41.75	0.11
Broadleaved Deciduous Closed to Open Forest	79.89	0.22
Needle-leaved Evergreen Closed to Open Forest	252.28	0.69
Total	36,594.26	100.00

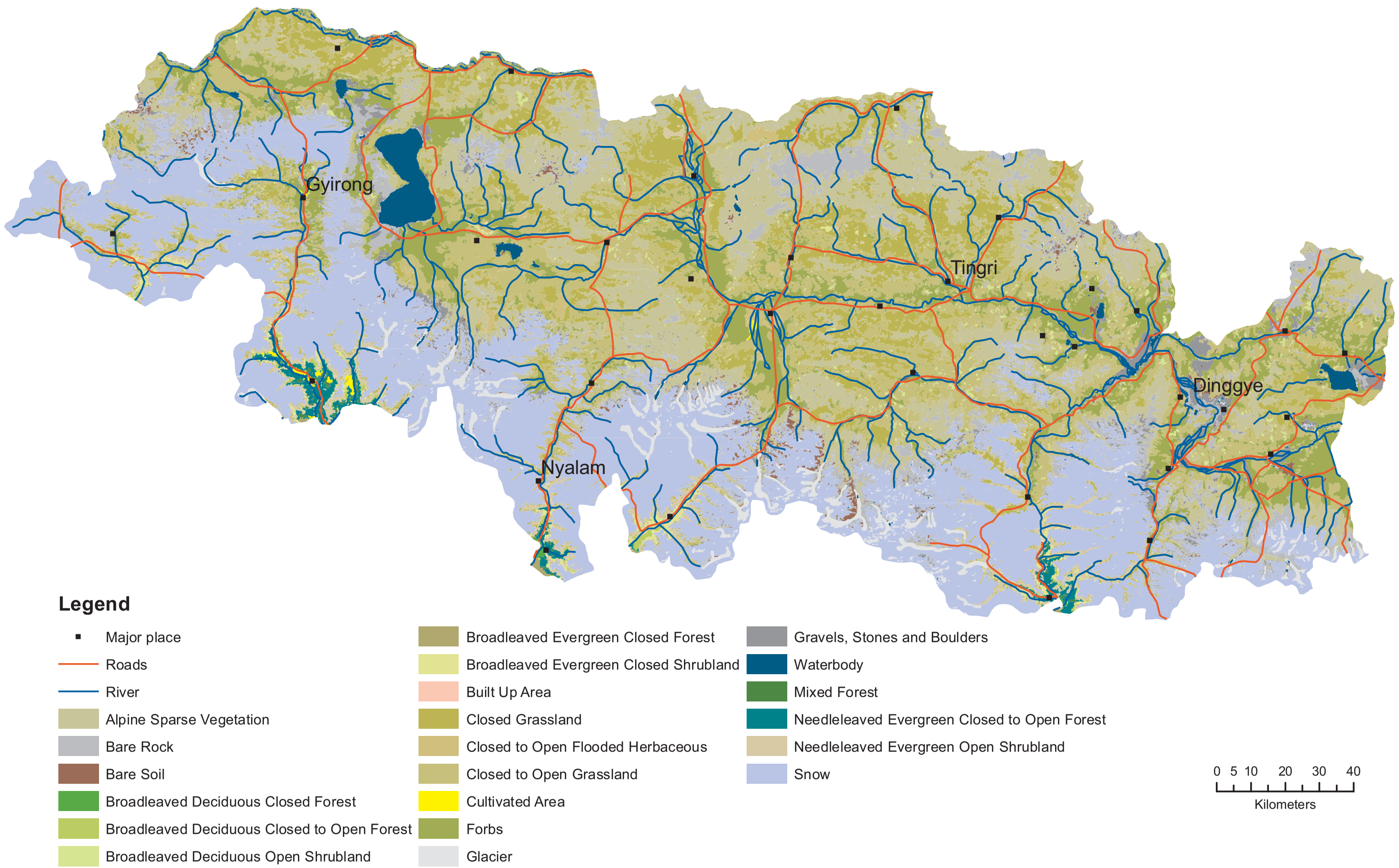


Figure 5.10: Land cover map derived from AWiFS image

Table 5.3: Summary of land cover types by elevation (AWiFS)

Classes	Elevation Zone (m)							Total (sq km)
	≤ 2000	2000-3000	3000-4000	4000-5000	5000-6000	6000-7000	≥7000	
Alpine Sparse Vegetation	0.00	0.00	0.00	215.51	5877.78	0.07	0.00	6093.36
Bare Rock	0.00	0.00	6.71	635.63	2020.52	65.50	0.27	2728.62
Bare Soil	0.00	0.00	2.01	57.18	123.06	14.72	0.00	196.96
Broadleaved Deciduous Closed Forest	0.58	12.37	1.56	0.00	0.00	0.00	0.00	14.51
Broadleaved Deciduous Closed to Open Forest	0.00	0.00	62.15	17.74	0.00	0.00	0.00	79.89
Broadleaved Deciduous Open Shrubland	0.00	0.00	2.25	180.20	16.71	0.00	0.00	199.16
Broadleaved Evergreen Closed Forest	3.87	11.31	2.87	0.03	0.00	0.00	0.00	18.07
Broadleaved Evergreen Closed Shrubland	0.00	5.28	136.87	71.47	1.25	0.00	0.00	214.87
Built Up Area	0.00	0.50	0.35	1.15	0.00	0.00	0.00	2.00
Closed Grassland	0.00	0.47	59.25	2937.10	850.93	0.00	0.00	3847.74
Closed to Open Flooded Herbaceous	0.00	0.00	20.55	301.31	88.65	0.00	0.00	410.52
Closed to Open Grassland	0.00	0.05	104.02	6044.69	409.67	0.00	0.00	6558.43
Cultivated Area	0.11	10.17	18.22	8.00	0.00	0.00	0.00	36.50
Forbs	0.00	0.00	59.94	4185.91	129.31	0.00	0.00	4375.16
Glacier	0.00	0.00	4.44	69.12	431.71	145.01	2.88	653.16
Gravels, Stones and Boulders	0.00	0.00	5.10	503.10	317.15	3.32	0.00	828.67
Lake	0.00	0.00	0.00	367.26	15.71	0.13	0.00	383.10
Mixed Forest	0.00	6.99	34.75	0.00	0.00	0.00	0.00	41.74
Needleleaved Evergreen Closed to Open Forest	0.05	92.32	159.73	0.14	0.00	0.00	0.00	252.24
Needleleaved Evergreen Open Shrubland	0.00	11.78	189.65	340.70	7.25	0.00	0.00	549.38
River	0.00	0.00	0.13	51.55	7.39	0.85	0.03	59.94
Snow	0.00	0.04	114.14	2465.24	5562.22	851.87	37.44	9030.95
Total (km^2)	4.61	151.28	984.69	18453.00	15859.31	1081.47	40.62	36574.97

Land cover from ASTER

The total area of the land cover data derived from ASTER around Mt. Qomolangma (Everest) is 2600 sq km. The statistical results of each land cover classification (Table 5.4) show the following: the biggest area is covered by bare rock, approximately 501 sq km (18.71%). Percentages of closed grassland, alpine sparse vegetation, closed to open grassland, glacier and snow are more than 10%, and their areas cover, 442 sq km (16.49%), 388 sq km (14.46%), 355 sq km (13.24%), 287 sq km (10.73%) and 282 sq km (10.50%) respectively. And the total area of shrub land makes about 57.68

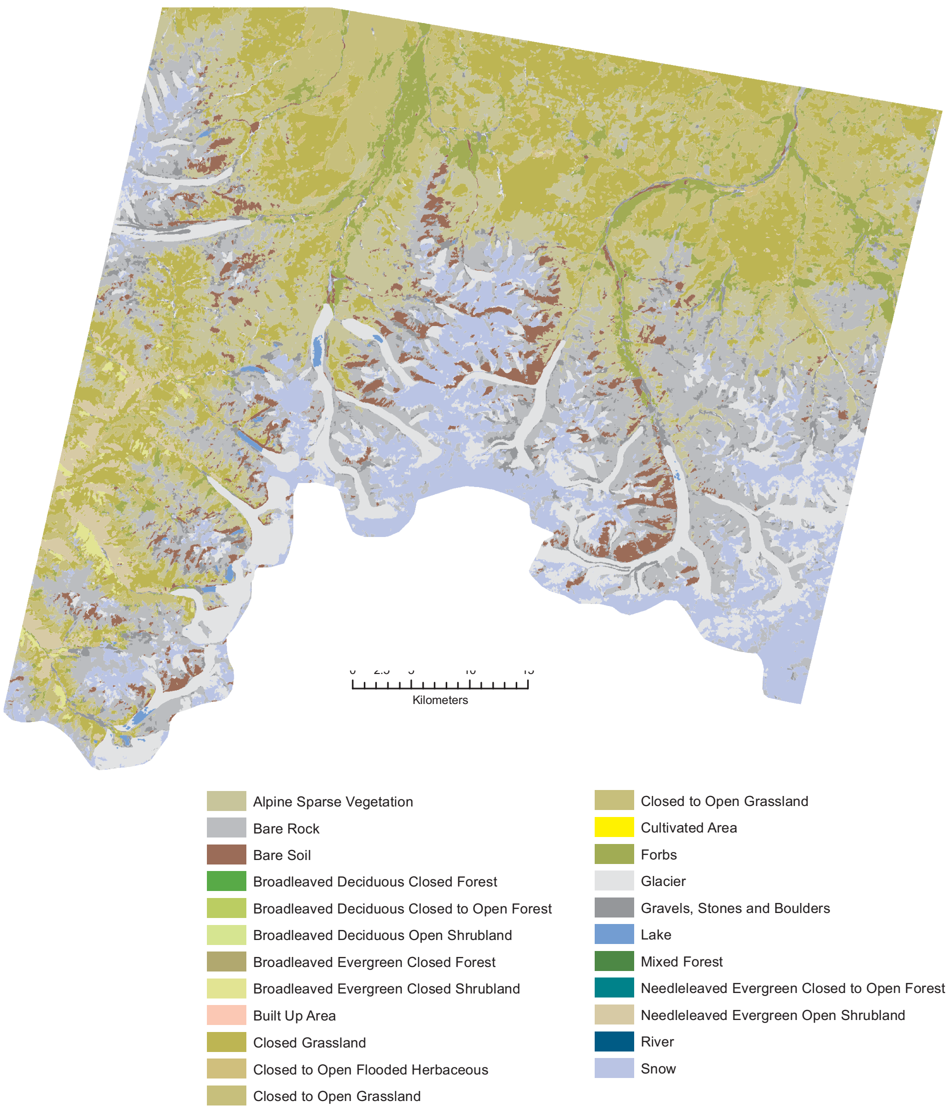


Figure 5.11: Land cover map derived from ASTER image

sq km (2.15%) and the biggest one of shrub lands is needle-leaved evergreen open shrub land. The total area of grassland including forbs, closed grassland, alpine sparse vegetation, closed to open grassland and closed to open flooded herbaceous is the largest in the area, approximately 1334 sq km with 49.75%. Bare area covers about 26.61% with area of 714 sq km consisting of bare rock, bare soil and gravels, stones and boulders. There is no river in the land cover map due to the spatial resolution and acquired time of ASTER image in winter.

Table 5.4: Statistics of land cover map derived from ASTER image

Type	Area (km^2)	Percentage (%)
Lake	7.07	0.26
Snow	281.53	10.50
Glacier	287.72	10.73
Bare Soil	106.01	3.95
Bare Rock	501.93	18.71
Gravels, Stones and Boulders	105.92	3.95
Alpine Sparse Vegetation	387.79	14.46
Forbs	120.97	4.51
Closed to Open Grassland	355.02	13.24
Closed Grassland	442.42	16.49
Closed to Open Flooded Herbaceous	28.27	1.05
Broadleaved Evergreen Closed Shrub land	11.75	0.44
Needle-leaved Evergreen Open Shrub land	45.93	1.71
Broadleaved Deciduous Closed to Open Forest	0.02	0.00
Total	2682.33	100.00

The tabulated statistics of land cover type from ASTER image in each elevation zone at interval of 1000m were achieved (Table 5.5). The results show the following: the areas above 6000m mainly consist of snow, bare rock, glacier, gravels, stones and boulders as well as bare soil; vegetation type between 5000m and 6000m are mainly alpine sparse vegetation and closed grassland that cover the bigger area; lakes are mainly located between 4000m and 5000m; grasslands of closed to open grassland, closed grassland and forbs make mainly the most area between 4000m and 5000m; Shrub lands mainly are distributed between 4000m and 5000 m; and the distribution of forest in the extent of ASTER image selected is very little.

Accuracy assessment

All sample points were selected using a simple random sampling design, with 500 and 400 points selected for the assessment of land cover maps from AWiFS and ASTER images, respectively, in the entire study area.

The methods of accuracy assessment can be divided into three major components. First, sampling and evaluation protocols for the reference data were developed. Second, individual interpreters independently evaluated the reference data, and differences between interpreters were analyzed. Third, interpreters worked as a group to develop a final reference data set, and this was used to evaluate the sources of disagreement between the reference data and the thematic map.

Table 5.5: Summary of land cover types by elevation (ASTER)

Classes	Elevation Zone (m)					Total (sq km)
	3000-4000	4000-5000	5000-6000	6000-7000	≥ 7000	
Alpine Sparse Vegetation	0.00	2.24	385.38	0.17	0.00	387.79
Bare Rock	0.02	23.63	357.69	116.76	3.83	501.93
Bare Soil	0.00	5.40	84.07	16.48	0.05	106.01
Broadleaved Deciduous Closed to Open Forest	0.01	0.01	0.00	0.00	0.00	0.02
Broadleaved Evergreen Closed Shrub land	0.44	10.94	0.38	0.00	0.00	11.75
Closed Grassland	3.12	206.20	233.09	0.01	0.00	442.42
Closed to Open Flooded Herbaceous	0.86	16.88	10.53	0.00	0.00	28.27
Closed to Open Grassland	2.06	294.79	58.17	0.00	0.00	355.02
Forbs	0.18	105.11	15.68	0.00	0.00	120.97
Glacier	0.00	8.21	179.29	99.54	0.68	287.72
Gravels, Stones and Boulders	0.04	19.79	75.37	10.59	0.12	105.92
Lake	0.00	2.20	4.85	0.02	0.00	7.07
Needle-leaved Evergreen Open Shrub land	2.06	42.65	1.22	0.00	0.00	45.93
Snow	0.00	1.56	65.88	187.85	26.25	281.53
Total (km^2)	8.79	739.61	1,471.60	431.41	30.93	2,682.33

Table 5.6: Error matrix of land cover map from AWiFS image

	Land cover points classified																	
	Classes	1	3	4	5	6	7	11	12	13	14	15	16	17	18	23	26	27	Total
Reference points	1	8																	8
	3		11																11
	4			116															116
	5			2	2		2												6
	6					7	2		1										10
	7				1	1	27	1											30
	11						5	77	1	3									86
	12						2		46	5									53
	13			1			2	5	2	85	6								101
	14							2	1	5	40	1		2					51
	15						1			1		3							5
	16												2						2
	17										2		1	6		1			10
	18									1	1				2				4
	23									1						2			3
	26												1				2		3
	27																	1	1
	Total	8	11	119	3	8	41	85	51	101	49	4	4	8	2	3	2	1	500

1 Lake
3 Glacier
4 Snow
5 Bare Soil
6 Gravels, Stones and Boulders
7 Bare Rock
11 Alpine Sparse Vegetation
12 Forbs
13 Closed to Open Grassland
14 Closed Grassland
15 Closed to Open Flooded Herbaceous
16 Broadleaved Evergreen Closed Shrub land
17 Needle-leaved Evergreen Open Shrub land
18 Broadleaved Deciduous Shrub land
23 Needle-leaved Evergreen Closed to Open Forest
26 Broadleaved Deciduous Closed to Open Forest
27 Mixed Forest

Each random point for accuracy assessment was interpreted with the help of available field photographs, useful non-field reference data (e.g., grassland and forest map of Xigaze) and high resolution images from Google Earth with the application of expert knowledge reasoning method. After the final reference data set was completed, the attributes of land cover map were imported to the attribute of reference data set and then the error matrix (Table 5.6, Table 5.7) was calculated by the method of tabulated table. The accuracy assessment is provided in following tables (Table 5.8, Table 5.9).

Table 5.7: Error matrix of land cover map from ASTER image

	Land cover points classified														
	Classes	1	3	4	5	6	7	11	12	13	14	15	16	17	Total
Reference points	1	1													1
	3		37	1											38
	4			36											36
	5				17	1	1								19
	6		1			12	1								14
	7					1	55			1					57
	11				1		1	57	2	2					63
	12							3	16	4					23
	13							3	4	51	2				60
	14					1		2		3	69				75
	15									1		5			6
	16									4			1		5
	17										1			2	3
	Total	1	38	37	18	15	58	65	22	66	72	5	1	2	400

1 Lake
3 Glacier
4 Snow
5 Bare Soil
6 Gravels, Stones and Boulders
7 Bare Rock
11 Alpine Sparse Vegetation
12 Forbs
13 Closed to Open Grassland
14 Closed Grassland
15 Closed to Open Flooded Herbaceous
16 Broadleaved Evergreen Closed Shrub land
17 Needle-leaved Evergreen Open Shrub land

Finally, the overall classification accuracy of land cover map from AWiFS imagery is 87.4%, and by comparison, land cover map from ASTER imagery has a higher overall classification accuracy because of better spatial resolution (from 56 m to 15 m), which reaches 89.75%.

Table 5.8: Accuracy of totals (AWiFS)

Classes	Reference Totals	Totals Classified	Correct Number	Producer Accuracy	User Accuracy
Lake	8	8	8	100.00	100.00
Glacier	11	11	11	100.00	100.00
Snow	116	119	116	100.00	97.48
Bare Soil	6	3	2	33.33	66.67
Gravels, Stones and Boulders	10	8	7	70.00	87.50
Bare Rock	30	41	27	90.00	65.85
Alpine Sparse Vegetation	86	85	77	89.53	90.59
Forbs	53	51	46	86.79	90.20
Closed to Open Grassland	101	101	85	84.16	84.16
Closed Grassland	51	49	40	78.43	81.63
Closed to Open Flooded Herbaceous	5	4	3	60.00	75.00
Broadleaved Evergreen Closed Shrubland	2	4	2	100.00	50.00
Needleleaved Evergreen Open Shrubland	10	8	6	60.00	75.00
Broadleaved Deciduous Open Shrubland	4	2	2	50.00	100.00
Needleleaved Evergreen Closed to Open Forest	3	3	2	66.67	66.67
Broadleaved Deciduous Closed to Open Forest	3	2	2	66.67	100.00
Mixed Forest	1	1	1	100.00	100.00
Total	500	500	437	-	-

Overall Classification Accuracy = 87.4 %

Table 5.9: Accuracy of totals (ASTER)

Classes	Reference Totals	Totals Classified	Correct Number	Producer Accuracy	User Accuracy
Lake	1	1	1	100.00	100.00
Glacier	38	38	37	97.37	97.37
Snow	36	37	36	100.00	97.30
Bare Soil	19	18	17	89.47	94.44
Gravels, Stones and Boulders	14	15	12	85.71	80.00
Bare Rock	57	58	55	96.49	94.83
Alpine Sparse Vegetation	63	65	57	90.48	87.69
Forbs	23	22	16	69.57	72.73
Closed to Open Grassland	60	66	51	85.00	77.27
Closed Grassland	75	72	69	92.00	95.83
Closed to Open Flooded Herbaceous	6	5	5	83.33	100.00
Broadleaved Evergreen Closed Shrub land	5	1	1	20.00	100.00
Needle-leaved Evergreen Open Shrub land	3	2	2	66.67	100.00
Total	400	400	359	-	-

Overall Classification Accuracy = 89.75 %

6

Discussion and Conclusion

Land use and land cover analysis are evolving as one of the most fundamental information system for the study of ecosystems, protected areas management and their functions (Roy and Tomar 2000, Li et al. 2006, DeFries et a.l 2007). The Himalayan region is known for its rich biodiversity and the human induced land use change is bringing alarming signals on the fate of its biological resources (Myers et al. 2000, Pandit et al. 2007). Changes in land cover and land use patterns are indicators for analyzing socioeconomic and natural processes (MEA 2005).

Land cover mapping requires significant resources and due to the gaps in harmonized legends, the investments in the past initiatives could not be properly used for change studies. Our consultative and participatory analysis revealed that there are differences in the use of legends across the project sites and the compatibility for comparison is limited. LCCS, where land cover classes are clearly and systematically defined making unambiguous differentiation by use of the classifiers, is the only system in operational use at present. The free LCCS software developed by FAO facilitates this process in a more systematic way and provides opportunities for customized interpretation of satellite images. The regional and national workshops brought together scientists and professionals from three project sites and many diverse fields—forestry, agriculture, ecology, natural resources, biodiversity and conservation—that changed the traditional approach of considering land cover mapping from the perspective of forestry alone. Such consultative and participatory approach in conservation planning brings additional values while working at a regional level and it makes the products useful for applications across the different disciplines (Kalibo and Medley 2007). The efforts made by the project in harmonizing land cover mapping in its three pilot sites has initiated the process of generating awareness about the concepts and capacity building in using the common tools for the conservation and management of protected areas.

Land cover mapping by remote sensing provides advantageous information for ecosystem study in a short time over a wide area. The availability of temporal data from satellites has greatly facilitated the studies of land cover and it is more significant in the mountainous areas where accessibility is very limited due to its extreme topography. However, the mountain areas present many complexities in applying the image interpretation and processing tools. Unavailability of cloud free images in the region limits the studies to mostly winter seasons. The ortho-rectification and classification of images are more difficult due to high variations in altitude and dark shadows. The emerging image analysis technologies have made it possible to assess the land covers more quickly, efficiently and accurately. The adoption of object-based image analysis has helped in improving the classifications. The methodology is being extended to other applications within ICIMOD and its partner institutions.

Apart from using LCCS at the project level, the effort to build consensus at the regional level to develop a harmonized and standardized land cover are currently in the developing process. In this regard, ICIMOD has already joined hands with FAO/GLCN to develop an institutional framework. The initial contact and cooperation among regional organizations have been established and the technical resources required for this initiative has already taken place through a regional workshop held in Kathmandu in 2008. The land cover classification that was carried out based on a harmonized and standardized legend and developed as a result of the regional workshop has already been transferred to the partners in the regional member countries for validation. The next step would be to build the capacity of the national partners in the regional member countries through a series of workshops and training to carry out this task at the national level. This will pave the way for the adaptation of LCCS as an international standard for harmonized land cover mapping of the whole HKKH region.

7

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Building partnerships for the HKKH region

The project "Institutional Consolidation for the Coordinated and the Integrated Monitoring of Natural Resources towards Sustainable Development and Environmental Conservation in the Hindu Kush-Karakoram-Himalaya Mountain Complex" (HKKH Partnership project) is a regional initiative aimed at consolidating institutional capacity for systemic planning and management of socio-ecosystems at the local, national and regional levels in the HKKH region. The project, supported by the Italian Cooperation, is implemented by International Union for Conservation of Nature (IUCN), CESVI, Ev-K2-CNR Committee and International Centre for Integrated Mountain Development (ICIMOD).

Web links:
http://www.hkkhpartnership.org
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