Chapter 1

Introduction

1.1. Remote Sensing

Remote sensing (RS) is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand and Kiefer 2000). The term remote sensing is restricted to methods that employ electromagnetic energy as the means of detecting and measuring target characteristics (Sabins 1978). It is the science of identification of earth surface features and estimation of their geo-biophysical properties using electromagnetic radiation as a medium of interaction. Spectral, spatial, temporal and polarization signatures are major characteristics of the sensor/target, which facilitate target discrimination (Navalgund *et al.* 2007). RS technique uses satellites (space borne) or aircrafts (airborne) to detect the earth surface (Lillesand and Kiefer 2000, Agrawal 2003). Earth surface data, as seen by the sensors in different wavelengths (reflected, scattered and/or emitted), are radiometrically and geometrically corrected before the extraction of spectral information. RS data—with its ability for a synoptic view, repetitive coverage with calibrated sensors to detect changes, observations at different resolutions—provide better information for natural resources management as compared to traditional methods (Navalgund *et al*. 2007).

1.2. Land Cover Classification

Our life is inherently tied with the vegetation and ground cover that surrounds us (NASA 2011). Knowledge of status and dynamics of land cover is necessary for sustainable use and management of natural resources. Term land cover relates to the type of feature present on the surface of the earth (Lillesand and Kiefer 2000). Food and Agriculture Organization (FAO 2000) defines land cover as observed (bio) physical characteristic on the earth surface. It corresponds to the physical condition of the ground surface, e.g. agriculture land, forest, urban etc. Understanding of the type and amount of land cover in an area is an important characteristic from the standpoint of understanding of Earth as a system (Sriharan *et al*. 2004). Land cover information is equally important in understanding physical condition of political/administrative area to conduct conservation and development activities (Cihlar 2000).

The primary purpose of classification is the description of the structure and relationship of groups of similar objects (Sokal 1974). Land cover classification involves grouping of components into homogeneous units on the basis of characteristics significant to the management of land resources. Land cover maps record the structure and make-up of a landscape. A map structure related directly to real features on the ground can help understand and interpret the environment. It shows the inter-connectivity of landscape features, their immediate context and the wider neighborhood in which environmental influences operate. This type of map helps to see how ecological principles can explain patterns of landscape diversity (Sharma *et al* 2003).

1.2.1. Remote Sensing for Land Cover Classification

Satellite remote sensing has become an important tool for land cover mapping. Land cover mapping is one of the earliest applications of remote sensing technology (Cihlar 2000, Foody 2002). Coarse, moderate to high-resolution satellite images are nowadays used for land use classification and mapping purpose (Atkinson and Aplin 2000). Spectral pattern present within the data of each pixel of image is used as the numerical basis for categorization of land cover. Different feature type manifest different combinations of digital numbers (DNs) based on their inherent spectral reflectance and emittance properties (Lillesand and Kiefer 2002). Classification of land cover type from satellite image is usually done by unsupervised classification or supervised classification or both of them (Zomer *et al.* 2001, Foody 2002, Foody *et al.* 2005, Aranha *et al.* 2008).

Selection of appropriate spatial resolution of remotely sensed image and appropriate classification method are vital components of the land cover analysis from RS/GIS (Atkinson and Aplin 2000, Foody 2002). GIS integrates maps prepared from the classification of images.

1.2.1.1. Image Classification for Land Cover Detection

I. Unsupervised Classification

In unsupervised classification the classifier identifies the distinct spectral classes present in image data (Panda 2005). It examines the unknown pixels in an image and aggregates them into a number of classes based on the natural grouping or clusters present in the digital number value. It does not use training data as the basis of classification. ERDAS Imagine uses the ISODATA (Iterative Self-Organizing Data Analysis Technique) for unsupervised clustering. ISODATA uses the minimum spectral distance formula to form clusters. The algorithm is robust and has the advantage that the clusters generated are not biased to any particular location in the image.

The analyst must compare the classified data with some form of reference data to separate land cover classes. (Lillesand and Kiefer 2000, Long and Srihann 2004)

II. Supervised Classification

Supervised classification is the process of using training samples, samples of known identity to classify pixels of unknown identity. There are three basic steps involved in typical supervised classification: training stage, classification stage and output stage (Lillesand and Kiefer 2000, Panda 2005). During training stage numerical data are collected from training sites on the spectral response pattern of land cover type. Classification stage involves comparing unknown pixels to the spectral pattern of training sites and assigning a class which looks most likely to a similar category. Output stage gives land cover classified image, which can be interpreted visually and numerically in the form of hardcopy graphic products, tables of area statistics and digital data files.

Combination of different classification system (usually unsupervised and supervised) is nowadays used in land use/land cover classification (Long and Srihann 2004). In this approach, spectral signatures are taken from the unsupervised classified image and ground training samples and are used to provide algorithm for supervised classification of image. Supervised classification of image is said to be more accurate over unsupervised classification (Foody 2000, Aranha *et. al* 2008).

III. Accuracy Assessment of Classified Image from Confusion Matrix

Accuracy assessment of classified image is usually done by confusion matrix or error matrix (Foody 2000, Lillesand and Kiefer 2000, Aranha *et al.* 2008, Baidya *et al*. 2009, Bajracharya and Uddin 2010). It is simple cross-tabulation of the mapped class label against that observed in the ground or reference data for a sample of cases at specified locations (Foody 2002).

Table 1: The confusion matrix for analysis of classification accuracy. The highlighted elements represent the main diagonal of the matrix that contains the cases where the class labels depicted in the image classification and ground data set agree, whereas the off-diagonal elements contain those cases where there is a disagreement in the labels. (Redrawn from Foody 2002**).**

		Predicted Class				
Actual Class		A	B	C	D	Σ
	A	N_{AA}	N_{AB}	N_{AC}	N_{AD}	N_{A+}
	B	N_{BA}	N_{BB}	N_{BC}	N_{BD}	N_{B+}
	C	N_{CA}	N_{CB}	N_{CC}	N_{CD}	N_{C+}
	D	N_{DA}	N_{DB}	N_{DC}	N_{DD}	N_{D+}
	Σ	N_{+A}	N_{+B}	N_{+C}	N_{+D}	N

Different accuracies can be calculated using following methods (Lillesand and Keifer 2000):

Producer accuracies-Producers accuracies are obtained by dividing no of correctly classified pixels in each category (major diagonal) by the number of training set pixels used for the category.

User accuracies-Users accuracies are computed by dividing the number of correctly classified pixels in each category by the number of pixels that were classified in that category

Overall accuracies- Overall accuracy is calculated by dividing total number of correctly classified pixels (sum of elements along the major diagonal) by the total number of reference pixels.

1.3. Remote Sensing in Vegetation Analysis

Remote Sensing has become instrumental in understanding temporal and spatial pattern of plant life too. Physiological phenomena of plants are reflected in morphology and these are sensed by remote sensing instrument rendering useful information to plant scientists to study them in different spatial and temporal scales (Wang *et al*. 2004, Xie *et al*. 2008).

There are different satellites available which monitor the earth regularly. Some of them provide data daily, weekly, biweekly, every 16 days etc. Moderate Resolution Imaging Spectroradiometer (MODIS) provide land surface temperature and emissivity data even at every 5 minutes (MODIS, 2011). Terra MODIS (Terrestrial Moderate Resolution Imaging Spectroradiometer) Vegeation index provide two vegetation indices (NDVI and EVI) in

1000, 500 and 250m of spatial resolution (MODIS, 2011) of terrestrial land. MODIS data are processed to provide well-quantified and calibrated data sets of the earth surface, corrected for instrument radiometry, geometric distortions, atmospheric attenuation and cloud effect (Justice *et. al*. 1998). The use of such data will improve our understanding of global dynamics and process occurring on the land surface, in the ocean and in atmosphere (Cohen and Justice 1999).

Vegetation index NDVI is derived from atmospherically-corrected reflectance in the red, and near-infrared wavebands. The product, NDVI is derived from bands 1 and 2 of the Moderate-resolution imaging spectroradiometer on board NASA's Terra satellite (GLCF, 2011).

1.3.1. NDVI

The Normalized Difference Vegetation Index (NDVI) is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not. Normalized difference vegetation index (NDVI) observations reflect leaf density, but are primarily indicators of process rates—photosynthesis and transpiration (IJRS 1986).

When sunlight strikes objects, certain wavelengths of this spectrum are absorbed and other wavelengths are reflected. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 µm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 µm). The more leaves a plant has, the more these wavelengths of light are affected, respectively. NDVI is calculated using red and near infrared band of electromagnetic spectrum constituting particular pixel of image.

NDVI= $\frac{N \quad -R}{N \quad +R}$

Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1); however, no green leaves give a value close to zero. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves. (NASA, 2010)

Generally, healthy vegetation absorbs most of the visible light that falls on it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light. Bare soils on the other hand reflect moderately in both the red and infrared portion of the electromagnetic spectrum (Holme *et al.* 1987). NDVI is highly sensitive to both canopy foliar and understorey chlorophyll content (Dawson *et al.* 2003).

NDVI has found a wide application in vegetative studies as it has been used in land cover classification (Brown *et al.* 1993, Evans *et al.*1993, Loveland *et al.* 1991, Sharma *et al.* 2003, Baidya *et al.* 2009, Bajracharya and Uddin 2010), estimation of crop yields (Wang *et al.* 2005, Xiao *et al*. 2006), pasture performance (Piao *et al.* 2007, Kawamura *et al.* 2003) etc. It is often directly related to other ground parameters such as percent of ground cover, photosynthetic activity of the plant, surface water, leaf area index and the amount of biomass (Prince 1991; Running and Nemani 1988; Tucker & Sellers 1986, Dong *et al.* 2003, Boelman *et al.* 2003., Wijaya *et al.* 2010).

1.3.2. NDVI and vegetations' trend analysis

Analyses of NDVI data help to understand the temporal trend of vegetations' biophysical character in different spatial scales. The NOAA/AVHRR, Terra, Aqua MODIS, and SPOT/VEGETATION sensors are often used for the observation of NDVI in a global scale (Townshend *et al.* 1984, White *et al.* 2002, Huete *et al.* 2002, Delbart *et al.* 2006). The data from these sensors can also be used in vegetation trend analysis in different regional and local scale (Tucker *et al* 2001, Chu *et al*. 2007, Baldi *et al.* 2008). Vegetation seasonal variation (phenology) is also depicted by NDVI as value of NDVI is different for different season (Kale *et al* 2002, Chu *et al.* 2007)

NDVI trend gives the trend of vegetation health and vegetation vigor or productivity. These factors are often directly related to climate (Ichii *et al.* 2001, Chu *et al.* 2007), if not anthropogenic factors (Kinyanjui 2010).

1.3.3. NDVI and Climate

The normalized difference vegetation index (NDVI) measures vegetation health and density using plant reflectance characteristics recorded by satellite imagery (Kinyanjui 2010). These reflectance characteristics are outcome of physiological processes of vegetations. Precipitation and temperature directly influence water balance, causing changes in soil moisture regime which, in turn, influences plant growth. Thus, soil moisture is widely recognized as a key parameter that links precipitation, temperature and NDVI (Wang *et al.* 2003).

> A significant correlation between inter-annual NDVI and temperature variation was recognized in the northern mid- to high latitude areas between spring and autumn. A significant correlation was also identified between the NDVI, temperature and precipitation in northern and southern semiarid regions. A comparison of global NDVI trends shows that NDVI increases in the northern mid- and high latitudinal zones are related to temperature rise, and NDVI decreases in southern semiarid regions are due to a precipitation decrease in the 1982 to 1992 (Iichii *et al.* 2002).

The time lags have strong influence in the correlation coefficient between total annual rainfall and NDVI (Prasad *et al.* 2005). The seasonal dynamics of the NDVI characterize the vegetation phenology which closely follows the annual precipitation cycle with the NDVI response exhibiting a lag period of 2-3 months (Ingram and Dawson 2005). In southern Africa rainfall and NDVI showed strongest correlation when NDVI monthly values were compared with preceding bimonthly rainfall (Richard and Poccard 1998).
Temperature is not as much correlated to NDVI as precipitation; still it is significantly correlated (Rundquist and Harrison Jr. 2000, Chu *et al.* 2007).

1.4. Rationale of the Study

Manaslu Conservation Area is one of the most remotely located Conservation Area of Nepal. Still it is very rich in natural resources and cultural uniqueness. Very few works have been undertaken to analyze the natural resources of this area. For sustainable management of natural resources, knowledge about land cover is of foremost importance. This work has tried to throw light on land cover situation of Manaslu Conservation Area. As it is based on empirical data it will be reliable source for planners to design appropriate conservation and development activities in MCA considering land cover map created from this work.

The forest ecology of this region is less explored. This work has considered five major forest types of this area to elucidate the productivity difference and productivity trend of each forest type. In Nepal, study of climatic variables on productivity of forest is virtually absent. This work has tried to fill that gap by analyzing different forests' response to climatic factors (Precipitation and Temperature) by using RS and GIS technique.

1.5. Research Questions, Hypothesis and Objectives

I. Research Questions

1. How is the land cover distributed in MCA?
2. How is the trend of vegetation productivity (vigor) of each forest type as depicted by NDVI?
3. Are there any differences in vegetation vigor among different forest types?
4. How are climatic factors related to NDVI?

II. Hypothesis

Forest is largest land cover of MCA and NDVI can be used to assess forest productivity and ecological role of climatic factor on vegetation.

III. Objectives

There are two broad objectives of this research. One is to perform land cover classification of Manaslu Conservation Area and another is to analyze vegetation health (vigor, productivity) trend as seen from NDVI trend.

Specific Objectives:

1. To classify land cover of Manaslu Conservation Area
2. To analyze the seasonal and temporal trend of NDVI of different forest type.
3. To find out whether there are any differences in vegetation vigor between the different forest types.
4. To find out the correlation of climatic factors to the vegetation greenness (NDVI) of different forest type.

Chapter 2

Study Area

2.1. Manaslu Conservation Area

The study area is Nubri valley of Manaslu Conservation Area (MCA). MCA comprises seven Village Development Committees (VDCs)—Samagaon, Lho, Bihi, Prok, Chumchet, Chhekampar and Sirdibas—in the northern part of the Gorkha district. The MCA lies in 28° 20'-28° 45' Northern latitude and 84° 29'-85° 11' Eastern longitude. All the Village development committees except the Sirdibas are bordered with China (Tibet) on the northern side. The elevation of the area ranges from 1,400m to 8,163 m asl (NTNC 1998). The MCA encompasses an area of 1,663 sq. km. with seven VDCs. There are about 9,000 inhabitants living in MCA. About 2,000 species of plants, 33 mammals, 110 birds, 3 reptiles and 11 butterfly species in 19 types of forest have been reported from the area (NTNC 2011).

2.2. Climate

Rainfall is in the form of summer monsoon usually lasting from June to September. A significant area of the MCA is surrounded by a series of high mountains/extension of the great Himalaya protecting it much from the southern monsoon cloud. Maximum temperature and minimum temperature recorded in Gorkha station is 33.4 ^{o}C and is 2.4 ^{o}C respectively from 2001 to 2009. Average yearly rainfall from 2000 to 2009 is 1582.17 mm.

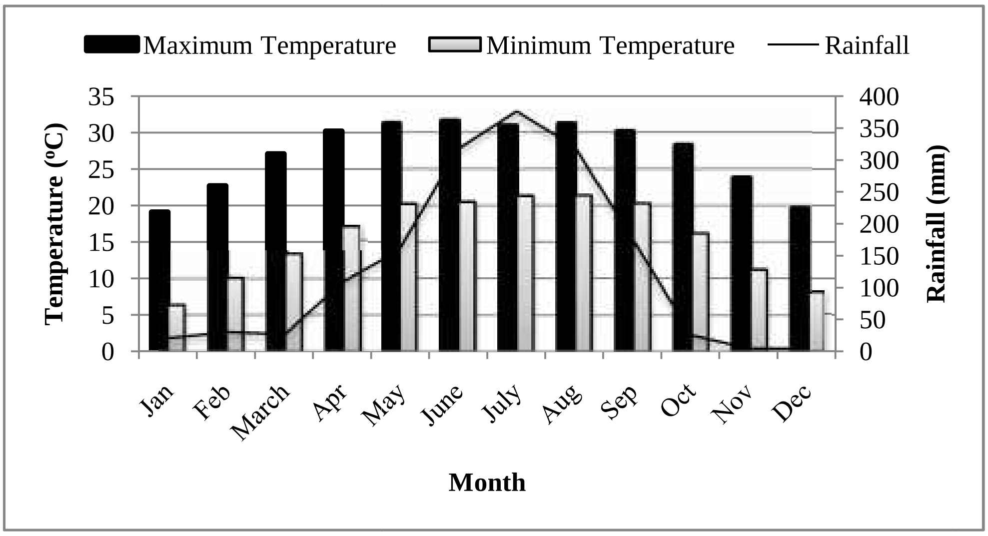


Fig 1: Graph showing seasonal variation of average rainfall (mm) and temperature (^{o}C) of Gorkha station. (Data source: DHM 2011). Graph includes 8 years average value from 2001 to 2008.

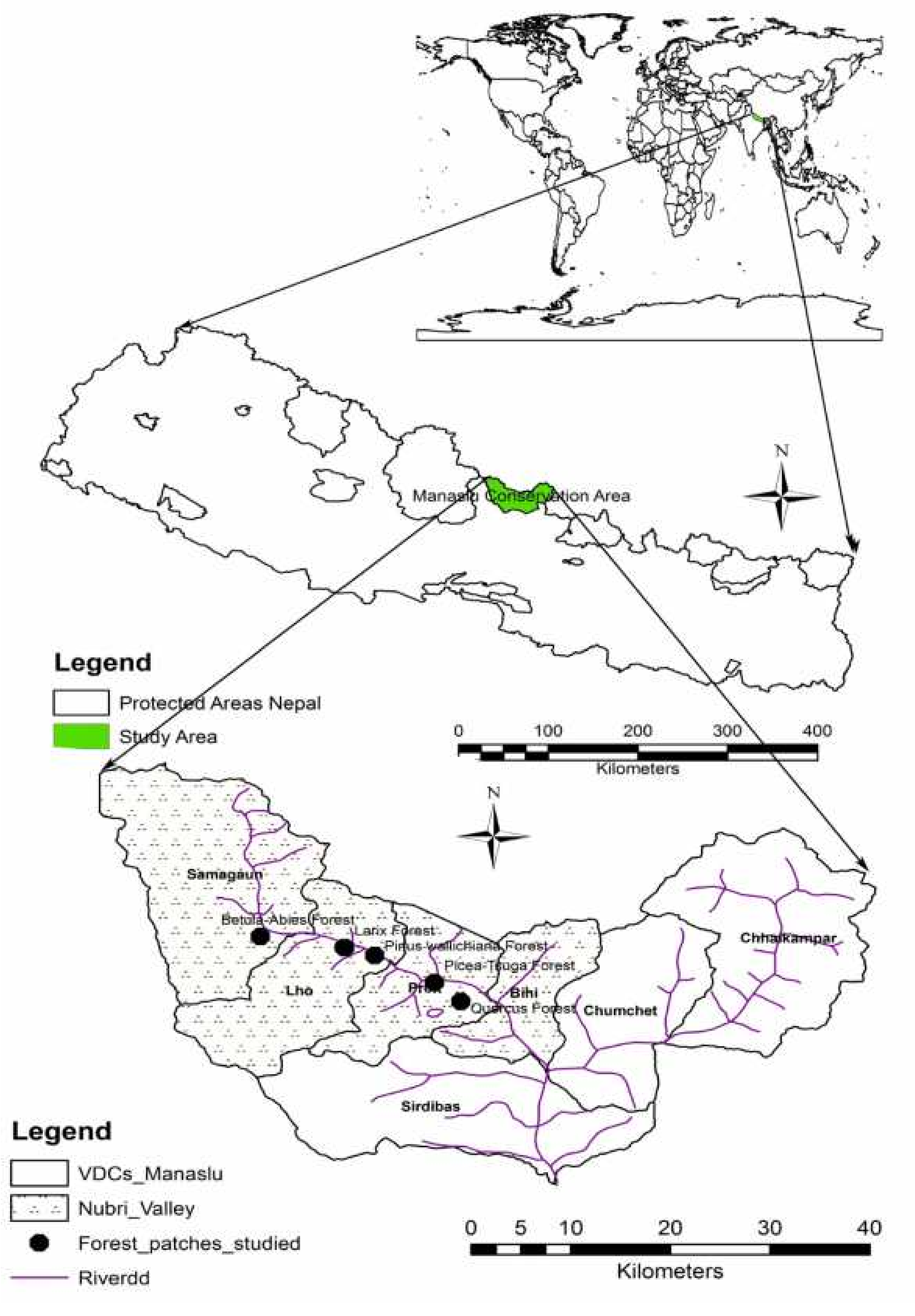


Fig 2: Map showing World, Nepal and Manaslu Conservation Area.

2.3. Ecology

From the general ecological viewpoint, the studied area is not very different from other areas of the country. The ecological zones are roughly representative of the country in general and its central zone in particular with sub-tropical, temperate, sub-alpine, alpine and nival zone extend roughly to 2,000m, 3,000m, 4,000m, 5,000m and above 5,000m, respectively. Budhigandaki is major River of this area. Nineteen (19) vegetation types are reported from Manaslu Conservation Area (NTNC 1998).

Vegetation types in Manaslu Conservation Area (NTNC 1998) are:

A. Low Hill Vegetation
   1. *Pinus roxburghii* forest
   2. *Schima-Castanopsis* forest

B. Middle Mountain Vegetation
   1. *Alnus nepalensis* forest
   2. *Quercus floribunda* forest
   3. Mixed *Quercus* forest
   4. *Pinus wallichiana* forest
   5. *Picea smithiana-Tsuga dumosa* forest
   6. *Quercus semecarpifolia* forest
   7. Mixed Hardwood forest: *Q. lamellose*, *Magnolia campbelli*, *Rhododendron arboreum*
   8. *Populus ciliate* forest

C. High Mountain Vegetation
   1. *Larix griffithiana* forest
   2. *Larix himalayica* forest
   3. Mixed *Larix* forest
   4. *Abies spectabilis* forest
   5. *Juniperus recurva* scrub
   6. *Betula utilis* forest
   7. *Rhododendron*-Juniper-Birch bushes
   8. Moist Alpine scrub
   9. Dry Alpine scrub

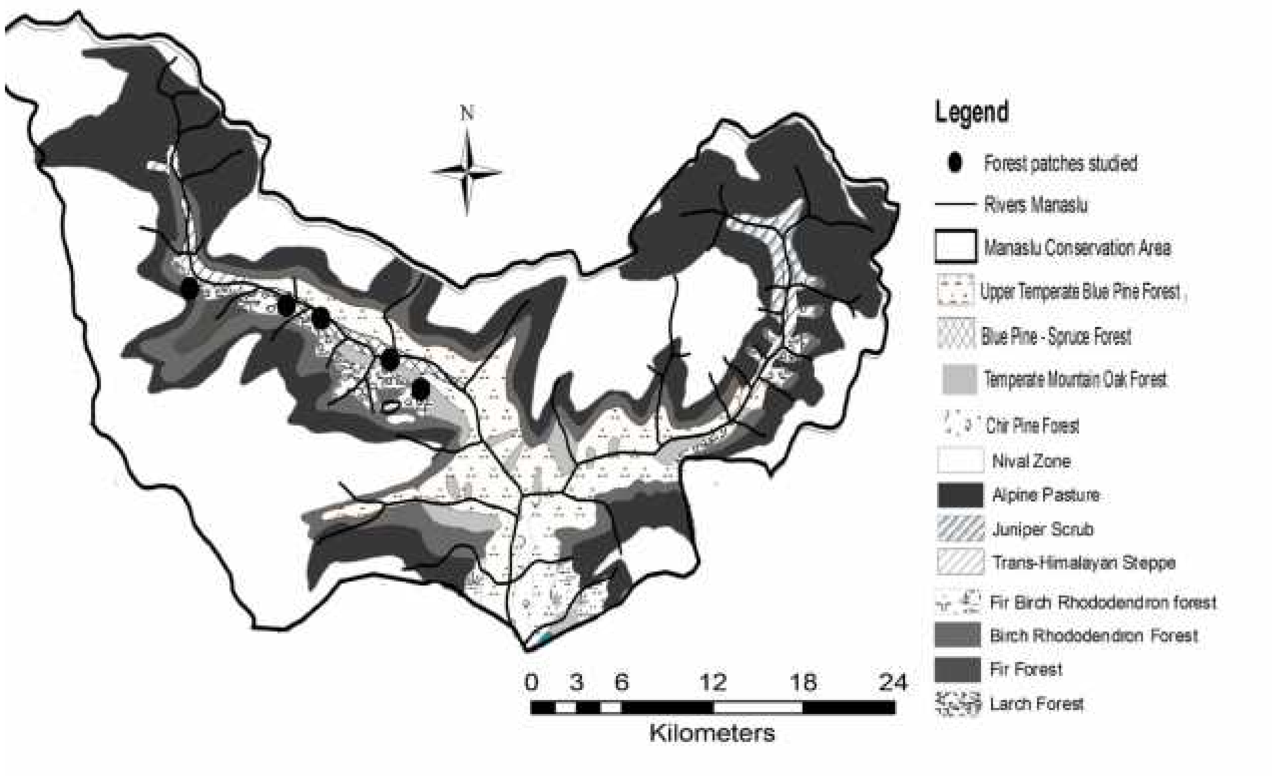


Fig 3: Map showing vegetation types in Manaslu Conservation Area (Map layers Source: MENRIS, 2010).

2.4 **Forest types studied**:

Following five forest types in Nubri valley of Manaslu Conservation Area was studied.

I. *Betula-Abies* Forest

This is typical alpine forest occurring above 3500m of altitude. The forest studied is from above Samagaon region, immediately on the foot of Mount Manaslu. This forest is dominated by *Betula utilis* with major association of *Abies spectabilis* and *Rhododendron campanulatum*.

II. *Larix* Forest

Himalayan Larch (*Larix himalayica*) is dominant in Lho village region of Nubri valley. It is typical subalpine river valley of Budhi Gandaki. *Larix himalayica* forest of same place was considered for analysis. *Larix* spp. are deciduous coniferous plant. Other associate tree species of this forest are *Abies spectabilis, Juniperus* spp., *Pinus wallichiana*, *Rhododendron arboreum, R. campanulatum* etc.

III. *Pinus wallichiana* forest

Blue pine (*Pinus wallichiana*) is dominant in some area of temperate belt of Manaslu Conservation Area. This species is mostly found as associated with many other forest types. There are very few species associated with this forest type as it tends to be monodominant. The Patch of forest taken for analysis consists of *Rhus* spp., *Pyrus pashia*, *Viburnum* spp., as associated species with *P. wallichiana*.

IV. *Picea-Tsuga* Forest

This is typical temperate forest exclusively located around Namrung village. *Picea smithiana* and *Tsuga dumosa* are dominant tree species while *Litsea* spp., *Sorbus* spp., *Alnus nepalensis,* etc are also associated with this forest.

V. *Quercus* Forest

Quercus forest studied lies in the southern belt of the Prok village. It is located on north facing very steep slope. *Quercus semecarpifolia* is dominant species while *Rhododendron arboreum, Lyonia ovalifolia,, Pieris formosa* etc are associated tree species.

Chapter 3

Materials and Methods

3.1. Materials

The research work was carried out with the help of following materials.

1. Reference data (In field with field data sheet, GPS, compass)
2. Satellite data: Landsat ETM+ of mid October 2009 and MODIS 16 days composite data of year 2000 to 2009
3. Climatic data: Maximum - minimum temperature of each month from 2001 January to 2008 December and monthly precipitation of year 2000 January to 2008 December
4. Software used

i. Microsoft Excel Worksheet for data entry and analysis

ii. Microsoft Word for writing thesis

iii. Microsoft PowerPoint for Presentation

iv. Remote Sensing and GIS software

   a. ERDAS imagine 9.1 for land cover classification, NDVI acquisition

   b. Arc GIS 9.3 for map preparation, cover area count

v. Statistical software

   SPSS 16.5

3.2. Methods

3.2.1. Methodological framework

This dissertation is completely based on Remote Sensing and GIS approach of natural resource study. Landsat ETM image of 30 m spatial resolution was taken for land cover classification. Five forest type of interest was delineated using land cover map and ground control points (GCPs). NDVI data of each forest patch was acquired from each 16 days composite image by using ERDAS imagine software. Monthly averaged NDVI data were calculated of year 2000 to 2008. These data were used for productivity analysis of these forest types. Climatic data were bought from Department of hydrology and meteorology (DHM, 2011) and these data were used for relation of NDVI with climatic variables.

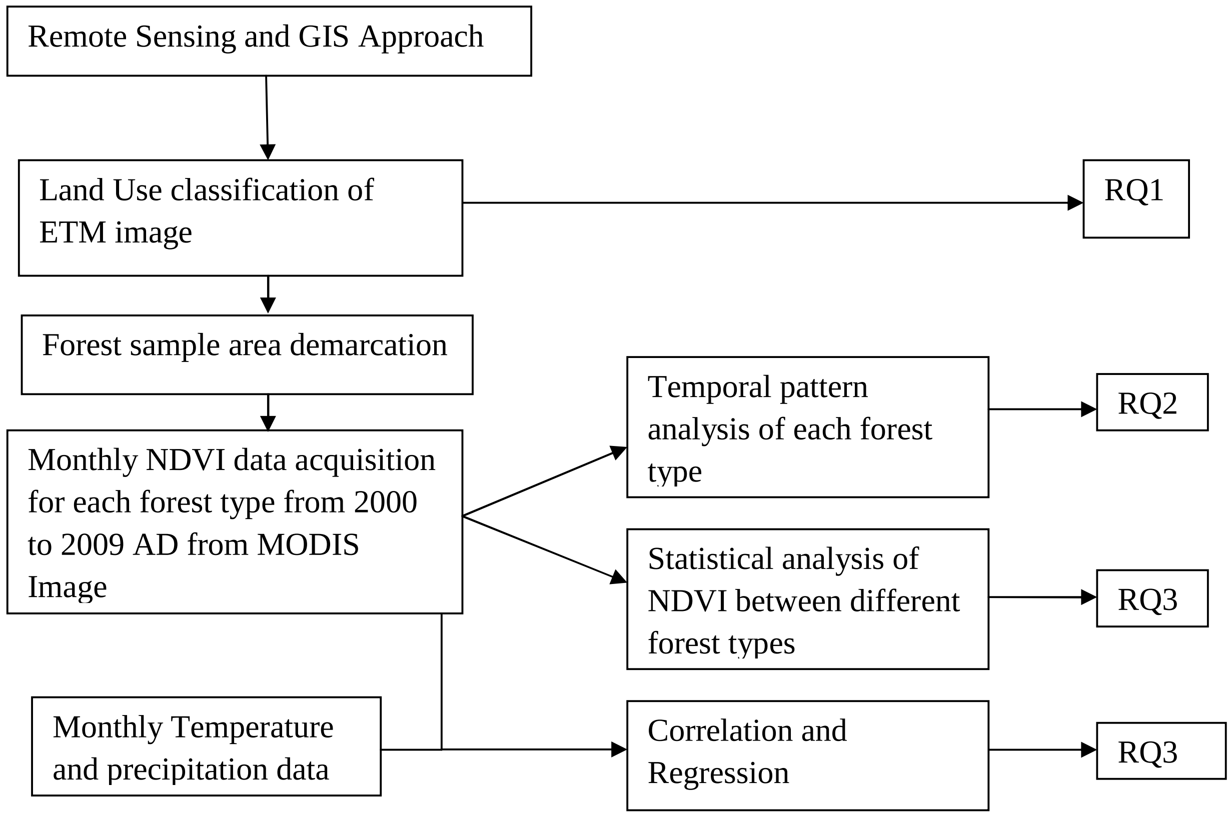


Fig 4: Flow Chart showing methodological framework of thesis work**.**

3.2.2. Land Cover Classification and Mapping

3.2.2.1. Reference data Collection

Reference data refers to field data for any remote sensing and GIS analysis. For this thesis work, reference data were collected in the field using random systematic sampling method using GPS and field data sheet (Appendix 1). Field study was done in 12th to 29th Dec 2009. Training data were collected in every 250 m along the trekking trail from Jagat to Larke Pass. Alltogether 287 ground control points were taken inside MCA. Collected data included latitude, longitude, UTM coordinates, altitude, land cover type, canopy coverage percentage of upper, middle canopy and ground vegetation with all the species occurred in each layer. Disturbances type like grazing, erosion, limb cutting, tree cut etc were also taken simultaneously in each ground control point.

3.2.2.2. Satellite data and processing

For land cover classification Landsat ETM image of 30 m spatial resolution date 2009, 311 (Julian date, mid October) was taken.

Remote sensing analysis in ERDAS imagine software requires image in imagine file (.img) format with different bands stacked over one another. TIFF images of different layers were stacked by layer stacking tool in ERDAS imagine software. Bands 1, 2, 3, 4, 5 and 7 are stacked upon one another. Band 6 was excluded as it is thermal band and its inclusion makes image file extra large. Image file hence layer stacked is in UTM-WGS 84 projection system, with 30 m pixel size.

Manaslu Conservation Area was cut out from the layer-stacked image by Area of Interest (AOI) and subset tool of ERDAS Imagine software. Shape file of outline of MCA was used as AOI to perform sub-setting operation.

3.2.2.3. Unsupervised classification

The subset Manaslu Conservation Area raster image was classified by unsupervised classification method. Using Iterative Self-Organizing Data Analysis Technique (ISODATA) algorithm given image was classified into 10 spectral classes with 10 iterations. GCPs and land cover analysis later revealed that classes 4 & 5 and 8 & 9 are of same land cover type. So class 4 & 5 were recoded as single classes 4 and class 8 & 9 were recorded as single class 7. Finally, there are seven land cover classes and one class remained unclassified.

3.2.2.4. Supervised Classification

Spectral signatures for supervised classification were taken from unsupervised classified image. There were seven land cover classes separated from the unsupervised classification. For each land cover type, the area coinciding map class and ground control point was selected to provide classification algorithm for supervised classification. AOIs of all land cover type were created and were added to signature file and a file was created containing spectral signature of all land cover type. The nearest neighbor and region grow method was adopted to create spectral signature of each cover class. During supervised classification, same signature file was used to classify the given image. Accuracy of supervised classified map was assessed by confusion matrix. Descriptions of land cover classes used in this work is given in Appendix 4

3.2.3. Productivity Study

Classified Landsat ETM image and Terra MODIS data products were used for the temporal and spatial analysis of vegetation health/vigor/ productivity of different forest type.

3.2.3.1. Forest Area Delineation

Our study is focused on Nubri Valley of Manaslu Conservation Area. In the second field visit, five forest types were identified for research. Second field visit was conducted during May 22 to June 1, 2010. *Betula-Abies* forest representing alpine forest, Larch forest (*Larix* sp.) representing deciduous subalpine habitat, *Pinus wallichiana* representing evergreen temperate coniferous forest, *Quercus semecarpifolia* forest representing temperate broad leaf forest and *Picea-Tsuga* as lower temperate conifer forest were selected for further analysis.
From the land use classified ETM image, comparable size of Area of interest (AOI) of each forest type was delineated.

3.2.3.2. NDVI data acquisition of each forest type

MODIS terra data products have NDVI as first layer of their data. Sixteen days composite data of 250 m pixel size of date 2000 January to 2008 December were used for NDVI trend analysis.

MODIS images were in Sinusoidal projection system and our AOI source (Landsat ETM image) was in Geographic UTM WGS-84, zone 45 projection system. Therefore, all MODIS images were reprojected to Geographic UTM WGS-84 zone 45 projection system prior to sub-setting operation. Sub-setting of reprojected MODIS image of each forest type was done from forest type AOI of Landsat ETM image.

From subset MODIS image of each forest type of every 16 days, NDVI was acquired by histogram tool of ERDAS Imagine. The NDVI value of each image of each forest type was entered in Excel worksheet.

For each forest type average NDVI of each month of all years (2000 through 2008) were calculated. These values were used to discuss seasonal and temporal pattern of vegetation greenness/vigor/ productivity.

3.2.3.3. Precipitation and Temperature Data

Monthly total precipitation and average temperature data of nearest weather station (Gorakha) of the year 2000 January to 2009 December were bought from Department of Hydrology and Meteorology, Government of Nepal. The precipitation and temperature data were used in correlation and regression analysis with NDVI for each forest type.

3.2.4. Data Analysis

3.2.4.1. Land cover data

Accuracy of land cover classification of supervised and unsupervised classification was assessed by Confusion matrix for each classification type. Confusion matrix was prepared by keeping real ground land cover type versus classified image land cover in a table. Land cover information obtained during first field study was used in assessing accuracy of classification method in cross tabulation matrix. Producers, users and overall accuracies of classified image were calculated from confusion matrix.

3.2.4.2. NDVI data analysis

The NDVI was acquired from the image of each 16 day. Average monthly NDVI was calculated from those values. Trend of NDVI of each year of each forest type was plotted. Average pattern of seasonality of NDVI was also plotted for each forest type. Similarly, trend of maximum and minimum NDVI of each forest type was also observed in graph. Mean NDVI values were compared between different forest types to assess productivity difference between different forest types.

3.2.4.3. NDVI and climatic variables

NDVI values of each month were undertaken into correlation analysis with temperature and precipitation. Correlation of NDVI with precipitation of same month, one-month lag, two-month lag and three-month lag were examined. Similar analysis was performed with temperature too. Regression analyses were also performed between best correlated climatic factors and NDVI.

Chapter 4

Results

4.1. Land Cover classification

Unsupervised and Supervised classification of ETM image of Manaslu Conservation Area was performed. The image produced after each classification is presented in figure 6.

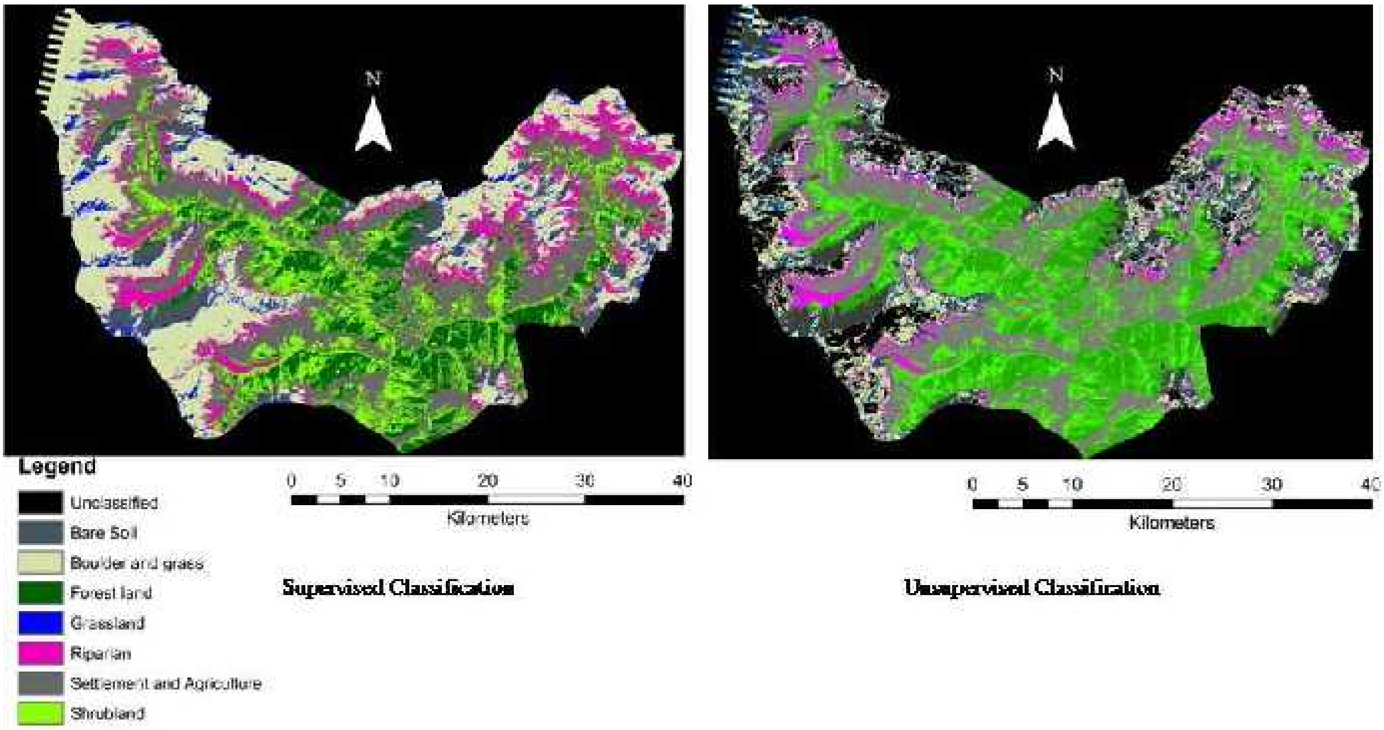


Fig 5: Map showing Supervised Classified and Unsupervised Classified images of Manaslu Conservation Area.

1.1.1. Accuracy assessment of supervised classification

Confusion matrix revealed that most of the classes are well represented in supervised classified map (table 2) with overall accuracy of 60.14%. But, grassland showed very poor accuracy. No Ground Control Point (GCP) depicting grassland cover shows same class in map. Bare soil also showed low accuracy. Only 31.25% of GCPs depicting bare soil actually are represented in map class as bare soil (Table 2).

Table 2: Confusion matrix showing Accuracy of Supervised Classification

Actual Class	Predicted Class									
		Forest	Shrub land	Settlement and Agriculture	Soil	Grass	Riparian	Boulder and Grass	Total	Producers accuracy
	Forest	11	6	3	0	1	0	0	21	52.38
	Shrub land	1	53	27	0	2	0	0	82	64.63
	Settlement and Agriculture	0	15	65	0	0	1	0	81	80.24
	Soil	1	3	6	5	0	0	0	16	31.25
	Grass	2	6	15	0	0	0	0	23	0
	Riparian	2	4	4	0	0	11	0	21	52.30
	Boulder and Grass	4	0	9	0	0	0	24	37	64.86
	Total	21	87	129	5	3	12	24	281	
	Users accuracy	52.38	60.91	50.38	100	0	91.66	100	**60.14%***	

* Overall Accuracy

4.1.2. Area of land cover classes

Among seven land cover types, Boulder & Grass occupies largest coverage in supervised classification system while Settlement & Agriculture land cover seems to be covering largest proportion of land in unsupervised system of classification. Grassland and riparian land cover occupy lowest coverage in MCA. Vegetated land cover (forest, shrubland/degraded forest and grassland) account for about 30% of total land cover which is equal to largest land cover Boulder & Grass. In unsupervised system of classification 8.56 % of land remained unclassified while all pixels were classified in supervised classification (Table 3).

Table 3: Area occupied by different land cover in different classification system

Land Cover type	Supervised Classification		Unsupervised Classification	
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)
Forest	197.82	12.34	268.21	16.74
Shrubland	215.53	13.45	232.14	14.48
Grassland	50.61	3.16	79.39	4.95
Settlement and Agriculture	419.31	26.17	440.98	27.52
Bare soil	104.38	6.51	130.63	8.15
Riparian	154.64	9.65	81.79	5.10
Boulder and Grass	460.24	28.72	232.05	14.48
Unclassified	0	0	137.32	8.56

4.2. NDVI Trend Analysis

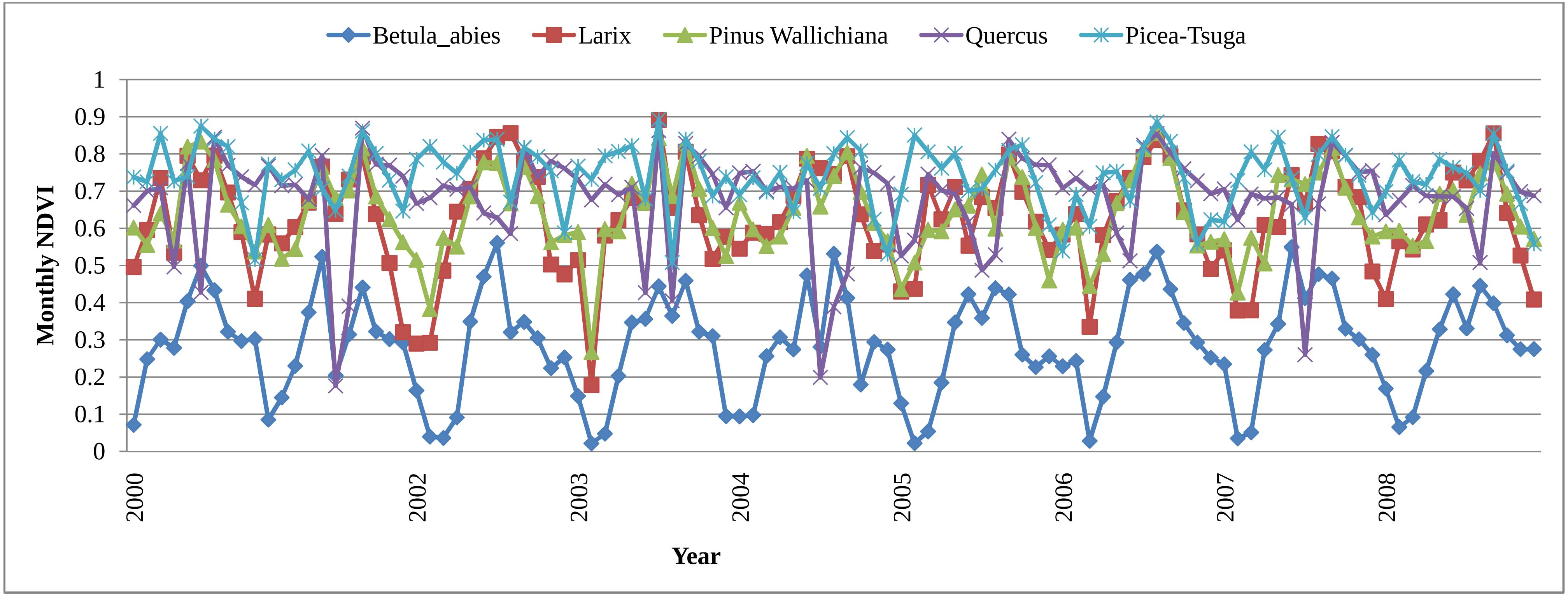
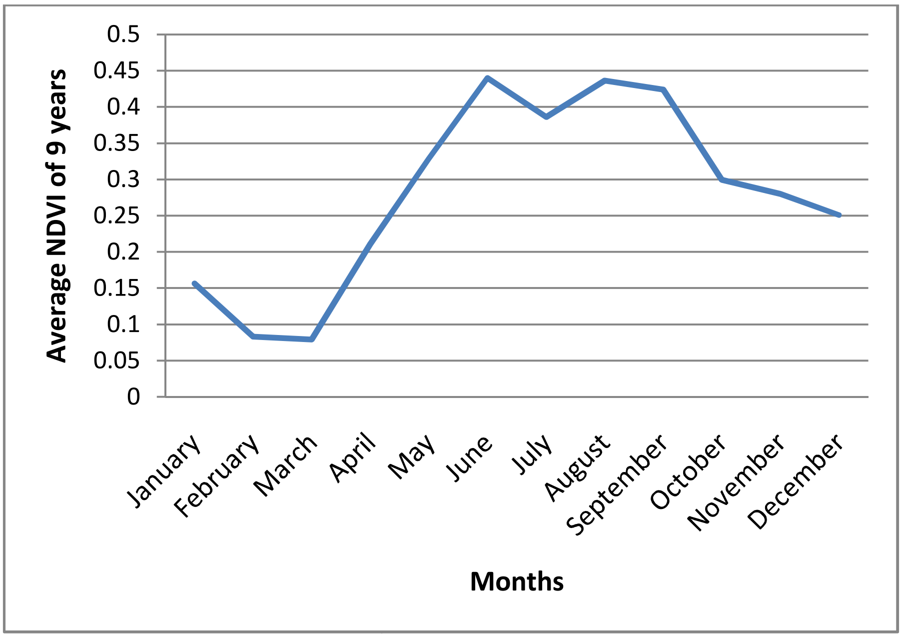


Fig 6: Monthly NDVI of Five forest type from 2000 to 2008

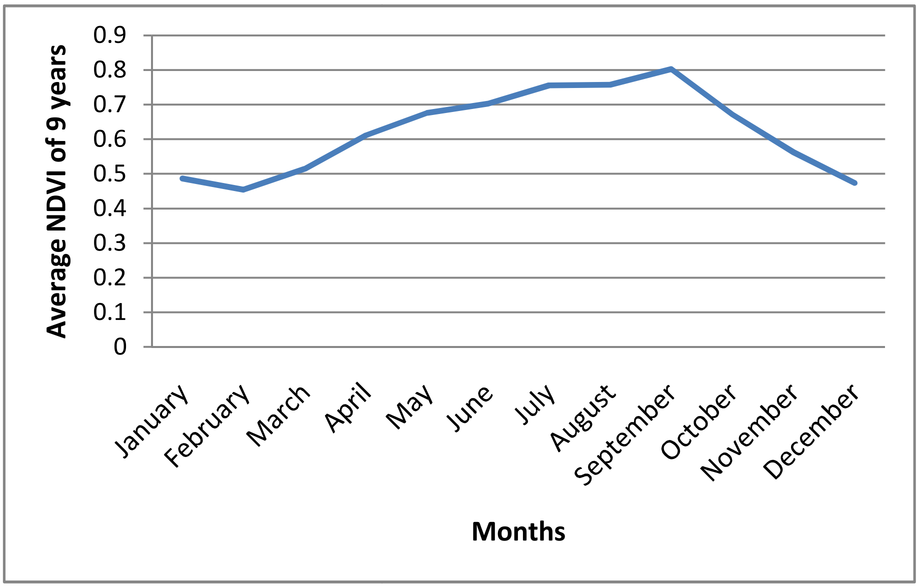
NDVI seasonal variation of each year of each forest type shows that there is peak around months of June, July, August and September while it decreases from October to May.

4.3. Seasonal NDVI trend

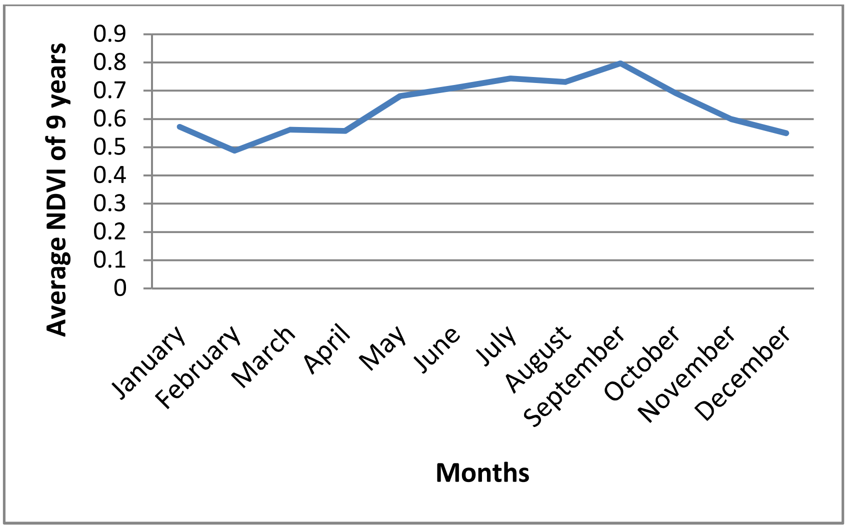
Normalizes difference Vegetation Index (NDVI) of all forest types have shown higher value during April to September coinciding with the growing period of vegetation of monsoon region, except *Quercus* forest, which have shown abnormal seasonal variation. Except the *Quercus* forest all forests have peak of NDVI immediately after rainy season during August and September. *Betula-Abies* forest has shown sharper seasonal variation than other forest.



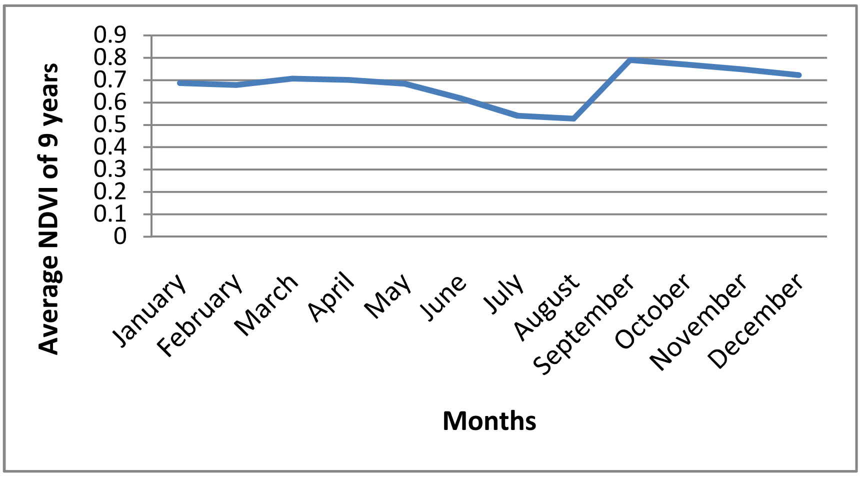
A1: *Betula-Abies* forest



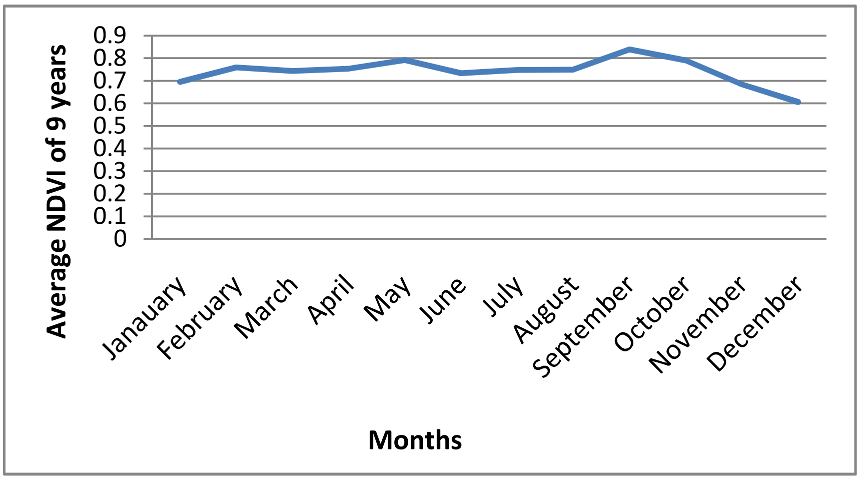
A2: *Larix* forest



A3*: Pinus wallichiana* forest



A4: *Quercus* forest

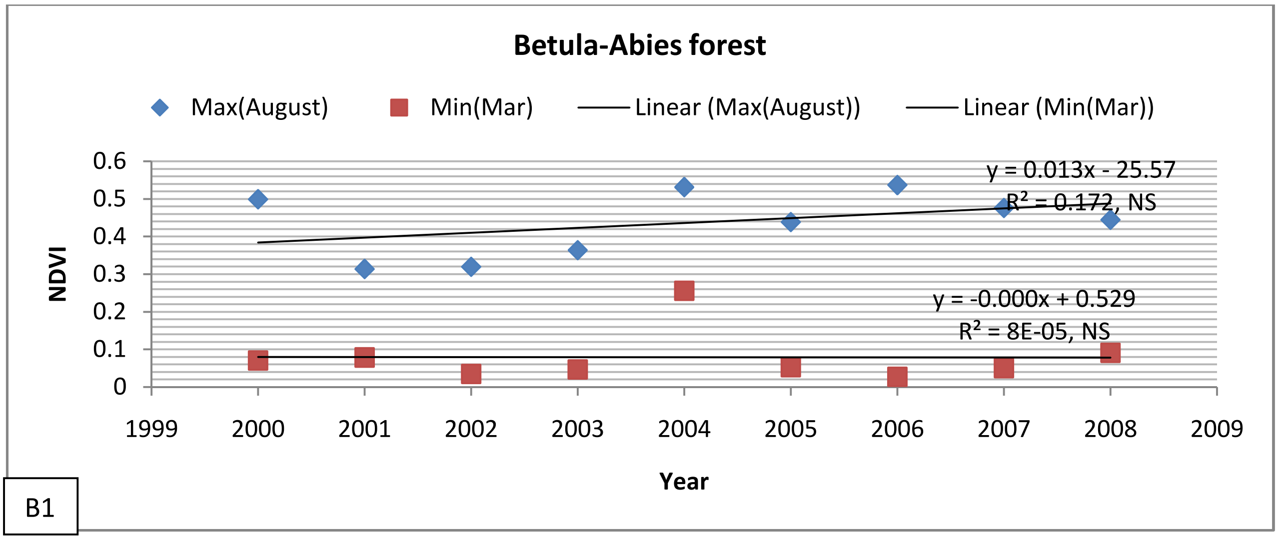


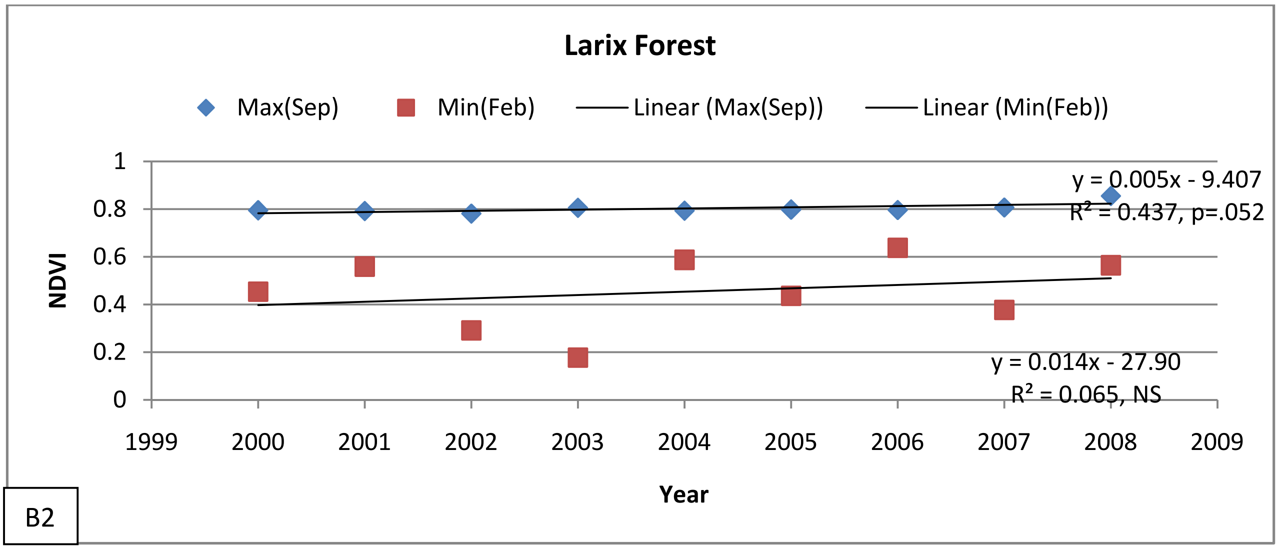
A5: *Picea-Tsuga* forest

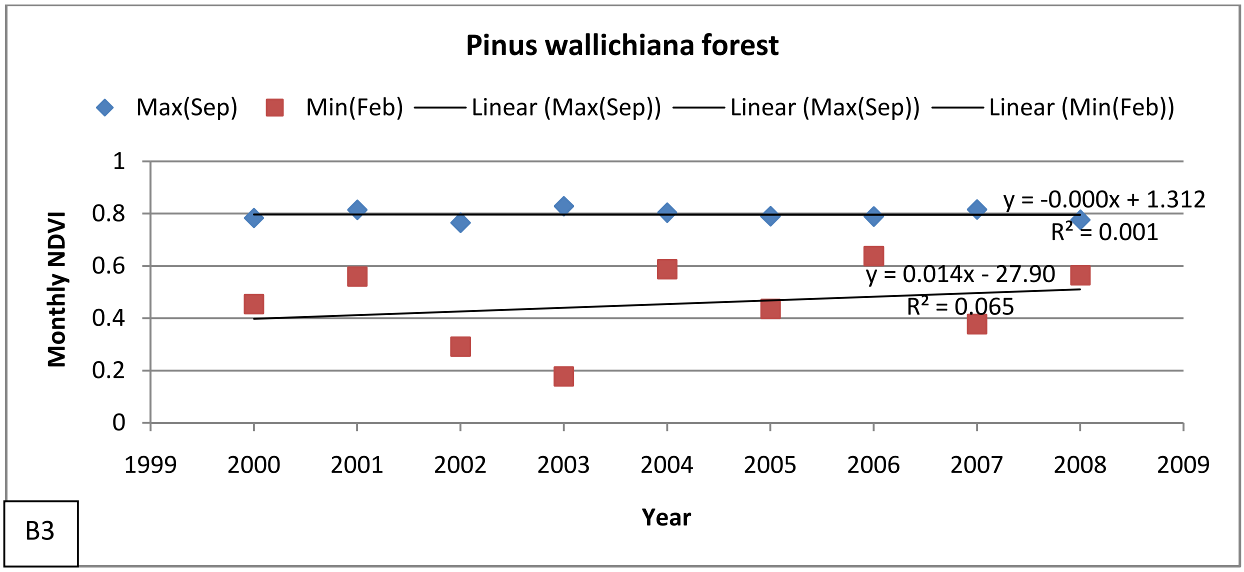
Fig 7 (A1 to A5): Seasonal trend of NDVI of each forest type. Nine years NDVI (2000 to 2008) values are averaged to get average NDVI of each month.

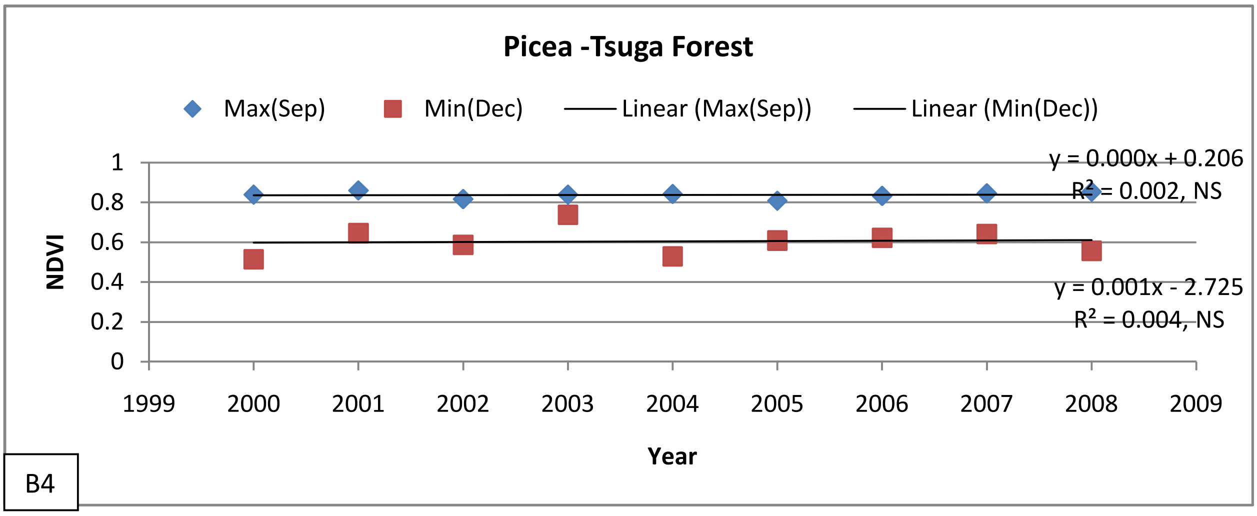
3.3. NDVI temporal trend

Among the 5 forest studied only maximum NDVI value of *Larix* forest depicted linear trend of increasing NDVI from 2000 to 2009. All other forest types did not show any significant trend of increasing or decreasing NDVI. *Betula-Abies* forest however showed linear trend but with low significance level. Interestingly no forest type showed any significant trend of their lowest NDVI value. These results assist us to infer that vegetation productivity/vigor or health is not changing over the time in MCA except in *Larix* forest.









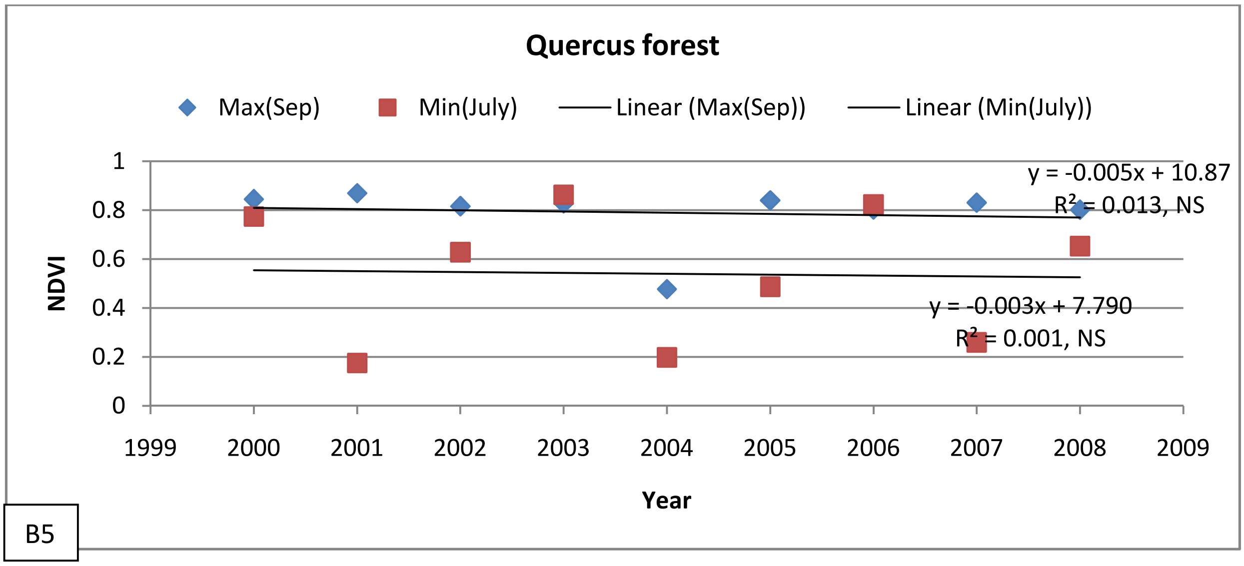


Fig 8 (B1 to B5): Trend of maximum and minimum NDVI of each forest type (**NS**- Not Significant, p value greater than 0.05).

4.5. Comparison of NDVI between different forest type

Mean NDVI for each forest type for study period is calculated.

Table 4: Mean NDVI with standard deviation (Mean ± SD) of 5 forest types.

S. N.	**Forest Type**	**Mean Monthly NDVI (2000 March- 2009 January)**
1.	*Betula-Abies* forest	0.29 ± 0.14
2.	*Larix* forest	0.62 ± 0.14
3.	*Pinus wallichiana* forest	0.64 ± 0.11
4.	*Quercus* forest	0.68 ± 0 .13
5.	*Picea-Tsuga* forest	0.74 ± 0.09

Picea-Tsuga>Quercus> Pinus wallichiana>Larix>Betula-Abies

ANOVA

The mean NDVI of some forest types are similar while some are different. Significance level of their mean differences has been tested by Analysis of variance (ANOVA).

Among the 5 different forest types studied in Manaslu Conservation Area, *Picea-Tsuga* forest has showed its healthiest and most vigorous status with highest mean NDVI. The highest NDVI value of this forest was statistically different from all other forest type. All other forest types showed statistically significant difference in mean to each other, except *Larix* and *Pinus wallichiana* forest. The NDVI values of latter two forests are not significantly different rendering similar productivity, health and vigor for this pair of forest.

Table 5: Table showing level of significance of difference in ANOVA analysis of NDVI between different forest types. ^{NS} in superscript indicates 'not significant' difference at 0.05 level of significance

	Betula-Abies	*Larix*	*Pinus wallichiana*	*Picea-Tsuga*	*Quercus*
Betula-Abies					
Larix	0.000				
Pinus wallichiana	0.000	0.307^{NS}			
Picea-Tsuga	0.000	0.000	0.000		
Quercus	0.000	0.003	0.02	0.000	

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4.6. Correlation analysis between climatic variables and NDVI

Monthly NDVI value of each forest type has been compared with monthly mean temperature and monthly total precipitation.

4.6.1. Temperature and NDVI

Correlation analysis between NDVI and temperature of same month and Temperature of preceding month was performed. Normalized Difference Vegetation index (NDVI) of *Betula-Abies, Larix and Pinus wallichiana* forest showed higher correlation with temperature of preceding month than that of same month. *Picea-Tsuga* forest and *Quercus* forest showed higher correlation with temperature of same month, and correlation coefficients are weaker than those of *Betula-Abies, Larix and Pinus wallichiana* forest types. NDVI showed better correlation to temperature than precipitation.

Table 6: Correlation coefficient between NDVI and Temperature. Shaded values represent highest correlation coefficient.

Forest type	**Correlation Coefficient between Temperature and NDVI**	
	Same month	**Preceding month**
Betula-Abies	0.621	0.784
Larix	0.723	0.756
Pinus wallichiana	0.634	0.760
Picea-Tsuga	0.39	0.253
Quercus	-0.164	-0.041

4.6.2. Precipitation and NDVI

Most of the forest type exhibited fairly good correlation between NDVI and precipitation. *Betula-Abies* and *Larix* forest showed highest correlation between NDVI of second month and sum of precipitation of 2 month. *Pinus wallichiana* and *Picea-Tsuga* forest showed highest correlation with third month NDVI and sum of precipitation of 2 month. *Quercus* forest NDVI showed odd relation with precipitation. It showed negative correlation with precipitation of same month. Correlation analysis between NDVI and Precipitation yielded following result (Table 7).

Table 7: Correlation coefficients between precipitation and NDVI. Shaded values represent highest correlation coefficient

Forest Type	Correlation coefficient between Precipitation and NDVI			
	Same month (1 vs 1)	Last month (1 vs 2)	Sum of two month vs NDVI of third month (1+2) vs 3	Sum of two month vs NDVI of second month ((1+2) vs 2)
Betula-Abies	0.603	0.597	0.64	0.665
Larix	0.60	0.663	0.69	0.70
Pinus wallichiana	0.55	0.666	0.718	0.676
Picea-Tsuga	0.229	0.272	0.336	0.276
Quercus	-0.477	-0.271	-0.156	-0.416

4.7. Regression analysis between NDVI and Climatic variables

i. Temperature and NDVI Trend

NDVI value of *Betula- Abies, Larix* and *Pinus wallichiana* forest shows strongest correlation with average temperature of last month. The trend line of all these forests shows initial decline of NDVI on increasing temperature and increase as temperature increase further.

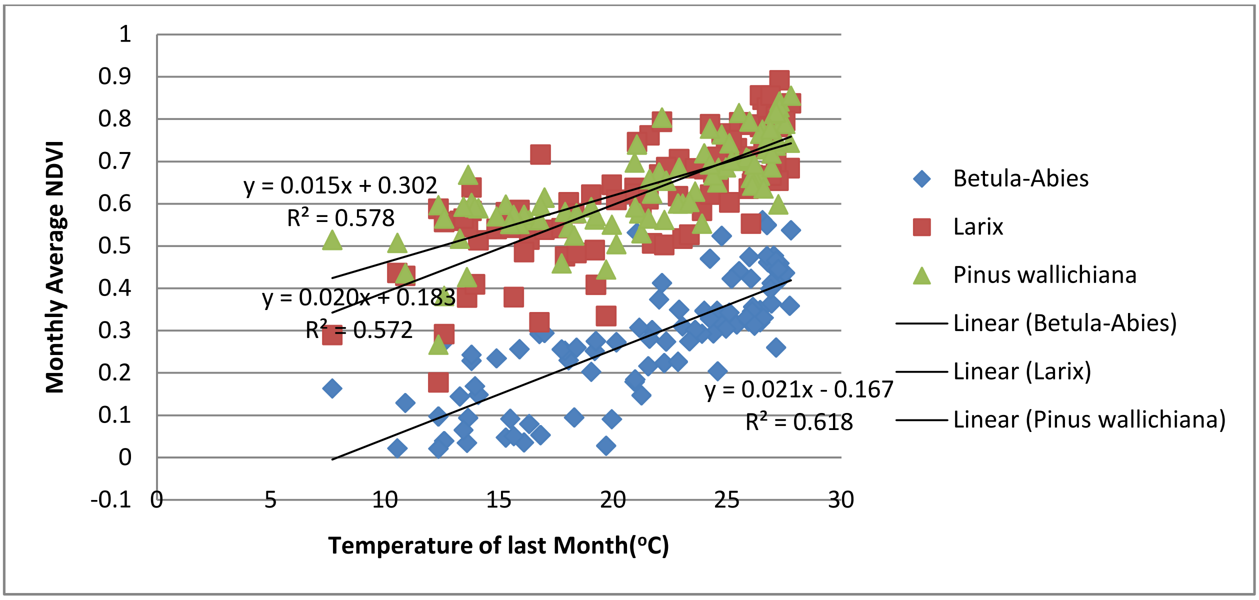

Fig 9: Regression scatter plots of Last Month's Temperature and Monthly Average NDVI of *Betula-Abies, Larix* and *Pinus wallichiana* Forest. Fitted line is linear model.

Average Monthly NDVI of *Picea-Tsuga* forest showed better correlation with Temperature of same month.

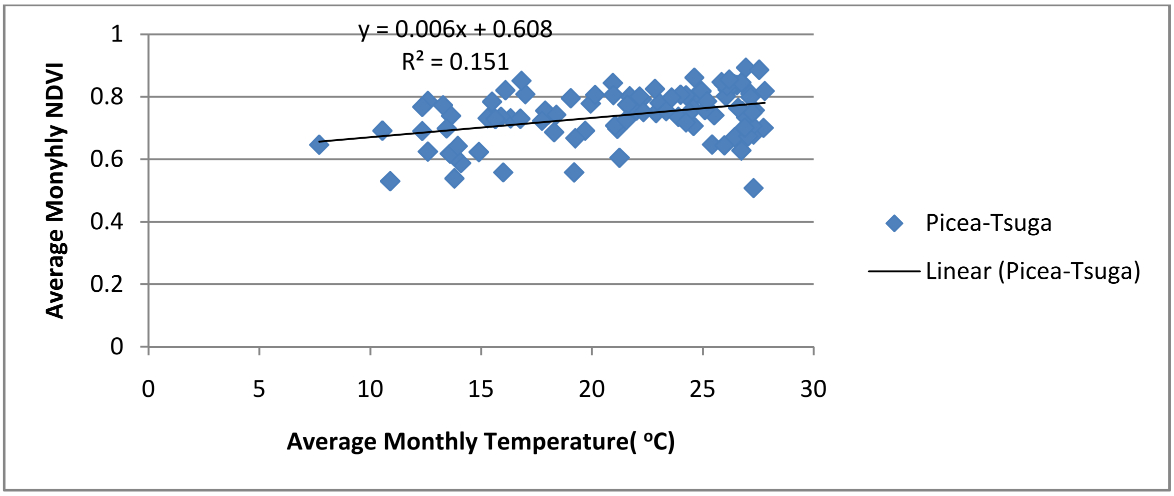

Fig 10: Regression scatter plot between average monthly temperature and average monthly NDVI in *Picea-Tsuga* Forest. The fitted line is based on linear regression model.

ii. Precipitation and NDVI trend

From correlation analysis, it is seen that monthly average NDVI of *Betula-Abies* forest and Larix forest shows strongest correlation to rainfall of two month. *Betula-Abies* and *Larix* forest NDVI showed unimodal relation with total rainfall of last two month. NDVI is maximum at 500-700 mm of cumulative rainfall of two month.

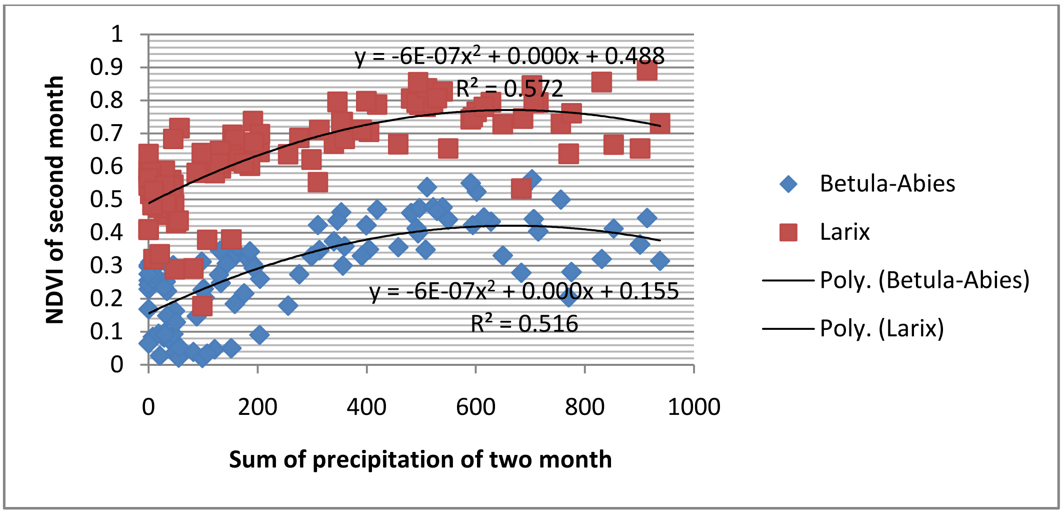

Fig 11: Regression scatter plots of two months total precipitation versus 2^{nd} month average Monthly NDVI in *Betula Abies* and *Larix* forest. Both fitted lines are based on quadratic regression model.

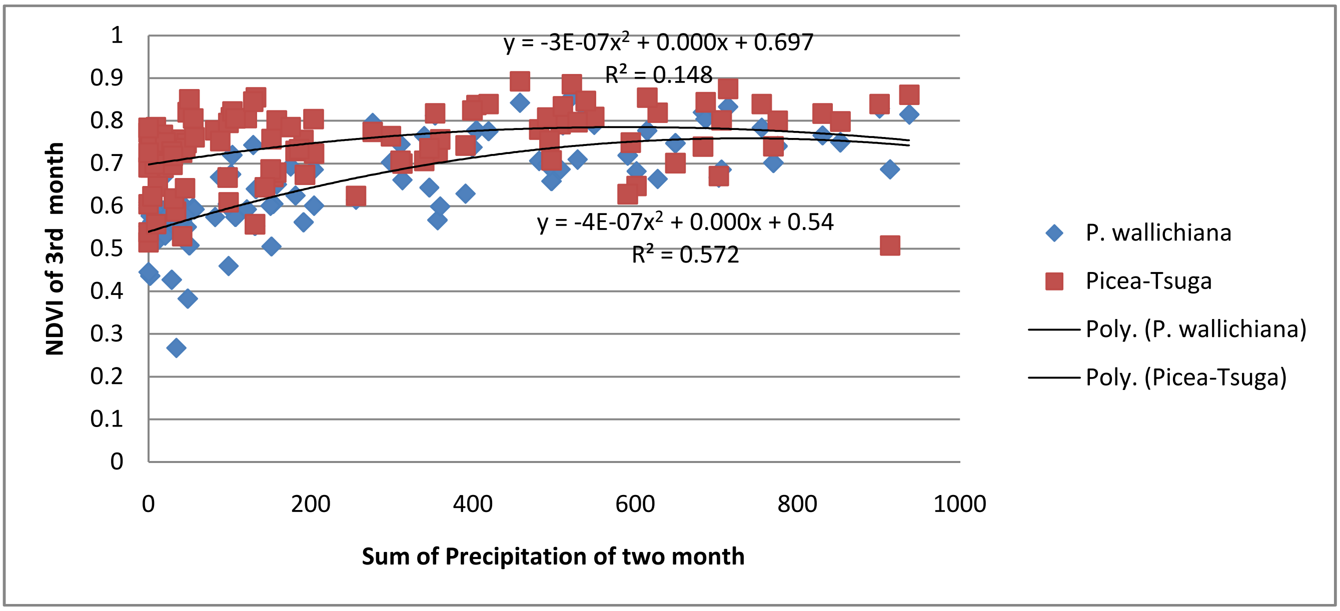

Fig 12: Regression scatter plots of two months total precipitation versus 3rd month average monthly NDVI in *Pinus wallichiana* and *Picea-Tsuga* forest. Both fitted lines are based on quadratic regression model.

Regression analysis reveals that NDVI is unimodally related to precipitation. NDVI of all forest types has clearly shown that NDVI is maximum at medium rainfall of 500 to 700 mm in 2 months. At higher rainfall, NDVI saturates and in extreme case, it decreases too. These graphs have clearly shown the ecological role and function of precipitation by revealing maximum vegetation growth and productivity at medium rainfall. Excessive rainfall either has no effect or may cause deleterious effect to the vegetation.

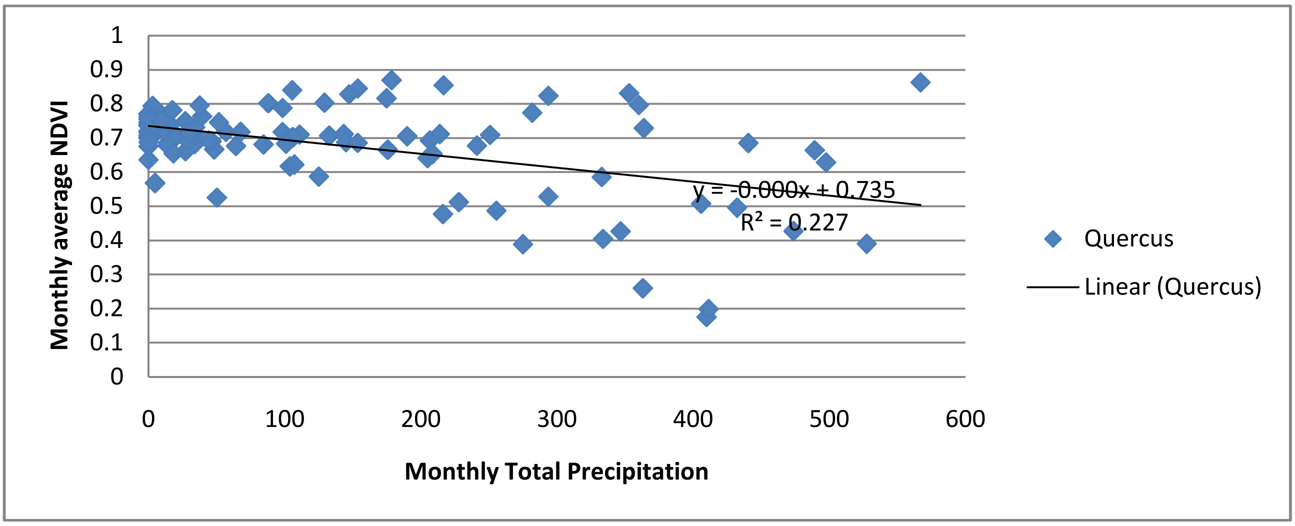

Fig 13: Regression Scatter plots of monthly total precipitation versus monthly average NDVI in *Quercus* forest. Fitted line is based on linear regression model.

Quercus forest shows opposite relation as compared to other forest types. Monthly NDVI of *Quercus* forest is best correlated with monthly precipitation of same month, and this relation is negative. The regression graph has also shown the decreasing trend of NDVI on increasing temperature. Though the best-fitted model is third order polynomial equation, the graph has clearly shown initial decrease in NDVI on increasing precipitation. This relation is quite odd.

Chapter 5

Discussion

5.1. Land Cover of Manaslu Conservation Area

Variations in topography, soil condition and climate result in spatial variations in land use in Manaslu Conservation area. Agriculture, settlement, forest, shrubland, pastures, grassland etc are major land use in trailside (McEachern *et al*. 1995). Influence of topography has been major cause of land cover differences here. Boulder and grass is seen as major land cover class in MCA and is followed by agriculture and settlement, which is outcome of anthropogenic influence. The vegetated land cover is still considerably high in MCA. The sum of forest and shrubland accounts for 25% of total land. The rugged topography, thin soil, extreme climate and anthropogenic influence are major factors behind this variation.

Among the seven land cover type, grassland is seen occupying smallest area (50 km^2) with only 3% of the total area of MCA. Official data however have shown greater share of grassland among different land cover type in MCA. Upper Gorkha (six VDCs constituting Manaslu Conservation Area now) had 7750 hectare (77.5 km^2) of rangeland in 1995 (McEachern et. al. 1995). The image we have analyzed is of the mid October of 2009. At higher elevations, grasslands are covered with snow for about half of the year. So some area of grassland might have been mistaken as riparian or snowland during the classification. Another important aspect of this difference can be attributed to the anthropogenic encroachment to the grassland. In some area, grasslands are ploughed and maize is planted on slopes having a gradient of even 45^o or more (McEachern *et al.* 1995, researcher's field study 2009, 2010). Similarity in spectral qualities between agriculture land and grassland also play significant role in mapping illusion because in dry season dried or grazed grasses and sparsely growing cropland may look similar in satellite image.

5.2. NDVI Seasonal Trend

The trend and magnitude of the NDVI values for the vegetation types are correlated with the spatial and temporal variability of precipitation (Chu *et al.* 2007, Gomez-Medoza *et al.* 2008). Months September and October are normally best growing period and April, May, and June are normally driest period in Nepal (Pradhan 2006). Forest types considered in this study have also shown distinct seasonal pattern of NDVI coinciding with the precipitation pattern with maximum NDVI during August, September and October. *Betula-Abies*, *Larix* forest and *Pinus wallichiana* forest have shown the similar pattern with maximum NDVI during rainy season, which includes warmer months too. *Quercus* forest and *Picea-Tsuga* on the other hand have shown odd pattern. *Betula-Abies* forest has shown very distinct peak (Fig 9, A1), revealing high altitude forests' response to the seasonal climatic cycle. The distinct seasonality of NDVI can also be related with the phenology and reflectance property of *Betula-Abies* forest in different season. *Betula utilis*, a deciduous tree, is dominant at this region. Consequently, this forest has lowest NDVI value during dry season.

Though Larix forest is deciduous, it has shown comparatively less steep graph (Graph 6, B2). Larix forest is mixed type of forest comprising *Abies spectabilis, Pinus wallichiana, Rhododendron* spp. etc. These are evergreen species, which add greenness even during the dry season. *Pinus wallichiana* forest is evergreen forest; still it has shown distinct seasonality in NDVI values. It is not only the physical greenness of canopy that determines NDVI, it varies with absorption of red light by plant chlorophyll and the reflection of infrared radiation by water-filled leaf cell (NOAA 2003).

5.3 NDVI temporal trend

Kawabata *et al.* (2001) extracted the following three distinct NDVI trends: In the northern mid- and high latitudes (e.g. Europe, Russia and northern China), a distinct increase in the NDVI was found for both the annual average and the spring to autumn period. In the equatorial regions (Africa and south-eastern Asia, excepting South America), a general increase was identified on an annual basis. In the Southern Hemisphere (e.g. Australia, Argentina), the NDVI has tended to decrease. This study though does not include Nepal Himalaya, it has shown that high latitudinal area had shown distinct increase in NDVI during 1982 to 1990. We have also analyzed trend of maximum and minimum NDVI for each forest type studied (Fig 9). As the study period is short (9 years), no forest shows statistically significant trend, but NDVI of *Larix* forest has shown very clear trend of increasing maximum NDVI (Fig 9, Graph B2). Other forests though do not show clear trend, *Betula-Abies* forest has shown increasing trend with r^2 value 0.123 (Fig 9, B1). These trends have affinity with the climate and anthropogenic influences and are directly associated to the use and management of forest resources in Manaslu Conservation Area.

The MCA was declared in the year 1998 and different conservation measures are being undertaken by MCAP (NTNC 2011). Still MCAP has not been able to decrease significantly the dependence of people to the forest products. Illegal felling down of trees is still imperative there. The trade of timber to Tibet is still practiced. An interesting fact this research reveals is that in spite of intensive use of forest resources by local people there has not been any significant decrease in NDVI value which indicates the non-degrading nature of patches of forest we studied.

5.4. Vegetation Vigor (NDVI) comparison between different forest type

Different vegetation types exhibit different NDVI value as depicted by reflection property of the crown of the particular vegetation type. NDVI is highly sensitive to both canopy foliar and understory chlorophyll content (Dowson *et al.* 2003). It is no doubt reflection of plant productivity. Different vegetation type depicts different productivity. Natural systems with more water availability are more robust (All 2009). Our analysis has revealed that *Picea-Tsuga* forest is with highest NDVI value among forest types studied. It is followed by *Quercus* forest, *Larix* forest, *Pinus wallichiana* forest and *Betula-Abies* Forest. The difference in mean NDVI value is significant between all forest pair except *Larix* and *Pinus wallichiana* forest. The mean NDVI value of this pair of forest is not significantly different implying similarity in productivity, vegetation vigor and health between this pair.

Betula-Abies forest we have taken is of highest altitude alpine forest. This is ecotonal forest of tree line. The trees are dwarf and sparsely occurring. That is why this forest is of low productivity. Winter snow, very low temperature during winter and low rainfall limit their productivity.

Larix and *Pinus waliichiana* forest are of nearer in occurrence and represent the same physiography of subalpine region. Their productivity that is why seems to be similar here. The life forms of *Pinus wallichiana*, *Larix himalayica* (dominant species) and *Abies spectabilis* (associated species) are same. They grow into comparable size during maturity. So, the productivity of these two forests looks similar. The anthropogenic pressure like felling of tree, limbing etc are also similar in both forest type as both are nearer to settlement (*Larix* forest is next to the Lho village while *Pinus wallichiana* forest is near to the Sho, Bhanjam and Namrung settlements).

Quercus forest we have studied is only broad-leaved evergreen forest. This forest lies in steep slope to the south of Prok village. Anthropogenic pressures, productivity of associated tree species and geography account for productivity variation here. Still broad leaves of *Quercus* spp., *Rhododendron* spp., *Lyonia ovalifolia* add more products to the ecosystem here so Quercus forest is seen as one of the highest productive forest ecosystems.

Picea-Tsuga forest is highest productive forest here. The forest we have studied actually is most vigorous in term of plant DBH and height. Most of the trees of this forest type exceed DBH of 1 m and are more than 30 m tall. This forest is of temperate region. Associated tree species like *Pinus* wallichiana, *Rhus* spp., *Viburnum* spp, *Acer* spp., Mosses and lichens covering the bark of every trees make this forest worthy of high productivity.

5.5. NDVI and Climate

Precipitation and temperature are primary controller of natural vegetation (Mather and Oshioka 1968, Rundquist *et al*. 2000) and climate has been called the ultimate ecological control. Vegetation vigor as exhibited by NDVI must also primarily depend upon these climatic factors. Precipitation and temperature directly influence water balance, causing changes in soil moisture regime that, in turn, influences plant growth. Thus, soil moisture is widely recognized as a key parameter that links precipitation, temperature and NDVI (Wang *et al.* 2003).

Similar result has been derived from this study. There is strong correlation between climatic factors (Precipitation and Temperature) and NDVI among all forest types (Tables 6 & 7). Contrary to general perception of better correlation of NDVI with rainfall, the forests studied here showed better correlation with temperature though correlation coefficients are comparable.

Correlation of NDVI to precipitation and temperature is also shown by number of previous studies in different parts of world. Chu *et al.* (2007) reported that there is strong correlation (r=0.75) between NDVI and precipitation in Lhasa Area of Tibet. Study of same Tibetan Platues' done by Mingjun *et al.* (2007) however reports that correlation between mean monthly maximum NDVI, and monthly precipitation from 1982 to 1999 is very weak in the western, northern and southern plateau, and very strong in the central and eastern plateau. Rundquist and Harrison Jr. (2000) studied Sandsage Prairie in Arkansas, USA and found that one month lag of precipitation is better correlated to NDVI however correlation coefficient of one month lag temperature is lower than that of same month. Prasad *et al*. (2005) studied different forest type in India and found that the correlation between mean monthly NDVI and precipitation is high with a lag of 30 days. Richard and Poccard (1998) analyzed the relationship between rainfall and the NDVI in southern Africa, and their study shows that the strongest correlations occur when NDVI monthly values are compared with preceding bimonthly rainfall amounts, attesting to a 1- to 2-month lagged vegetation growth response to rainfall. In grasslands of upper Mustang region of Nepal, Paudel and Anderson (2010) found a very strong relationship ($r=0.823$, $p<0.001$) between each 15 days NOAA NDVI between September and November (1981–2006) and the 12 months accumulation precipitation ending 15 days before the date of each NDVI image.

All major forest types (*Betula-Abies*, *Larix* and *Pinus wallichiana*) show steady incline of NDVI on increasing temperature of last month (Fig 12). A one-month lag of temperature has showed best correlation with NDVI. It has clearly revealed vegetations' physiological response to the temperature. The heat energy (measured as temperature) is used and expressed as productivity of vegetation in one-month period of time. This period shows the time of physiological activity of using climatic heat to inner system of plant.

Temperature is seen as limiting factor for vegetation growth and productivity because there is increase in NDVI even in highest value of temperature (Figs 11 & 12). If temperature had increased further, it would have yielded more NDVI value.

NDVI has shown slightly different relation with precipitation. NDVI values of four forest types *(Betula-Abies, Larix, Pinus wallichiana* and *Picea-Tsuga*) have shown unimodal relation with sum of precipitation of two month (Figs 13 & 14). There is higher NDVI value at medium rainfall of 500 to 700 in two month. Higher rainfall however has shown decreasing effect to the NDVI. These results are in accordance to the precipitations' general effect to the vegetation. Water percolated to the root zone of plant is only used by the plant and this necessity is fulfilled by certain amount of rainfall (500 to 700 mm in 2 months in Manaslu Conservation area forest). Excess rainfall either floods into the stream/river or may cause flooding around rhizosphere of plant that may limit availability of soil nutrient and eventually negatively affect the plant growth and productivity.

Two month accumulated rainfall is seen as best predictor of NDVI in four of the forest types. This period involves raining, sufficient amount of water accumulation around rhizosphere, uptake of water by plant and its use in various physiological processes. This research reveals that in two month of period high mountain forests can undertake those activities for maximum productivity if they get sufficient amount of rainfall. Important factor behind this time lag is translatory flow; movement of water from rainfall to soil to the water table (Horton *et al.* 1965, Brook *et al*. 2010).

Chapter 6
Conclusions

The result from this analysis shows strength of Remote Sensing and GIS technology to classify land cover for sustainable and efficient management of Land Resource. Even in the rugged terrain like Manaslu Conservation Area Supervised classification of ETM image yields reliable land cover map. This work has also been able to throw light on land cover situation of Manaslu Conservation Area. Land cover classification is first and foremost step in sustainable Land Management. Land Cover situation of Manaslu Conservation area has clearly revealed the dominance of rugged terrain as Boulder Grass as major land cover. This is followed by Agriculture and Settlement, which actually is human influenced landscape. Therefore, we can conclude that there is significant influence of anthropogenic factor on Land cover situation of MCA.

NDVI is indicator of productivity, vigor, health vegetation. From our analysis of NDVI of 5 different forest type we have found that vegetation productivity is almost not changing over the period of time from 2000 to 2008 except *Larix* forest which has shown significant trend of increasing of maximum NDVI. NDVI of *Betula-Abies* forest also shows positive linear trend however, significance level and R^2 values are lower in this case

Seasonal pattern of NDVI is in accordance with seasonal pattern of temperature and precipitation with highest NDVI value during growing period (June to September) in most of the forest type. The *Quercus* and *Picea-Tsuga* forests have however shown odd pattern.

Climatic factor always has great affinity to the productivity of any vegetation. Vegetations in Manaslu area in fact are not exception. All forest types show significant correlation to the temperature and precipitation. Interestingly NDVI values show greater correlation to temperature than to precipitation. Time lag of climatic factors happens to be important factor in determining productivity. *Betula-Abies*, *Larix* and *Pinus* forest NDVI shows greater correlation to the average temperature of preceding month while *Picea-Tsuga* and *Quercus* forests show greater correlation to the temperature of same month. These results clearly depict the vegetations' response to temperature as determined by their physiological activities. Clearly linear trend has been seen in NDVI response to temperature. Temperature as limiting factor is clearly seen in this part of Central Himalaya forest.

In case of precipitation, 2 months total precipitation is found as best predictor of NDVI of third month in case of *Betula-Abies* and *Larix* while that of second month in *Pinus wallichiana* and *Picea-Tsuga* forest. Here *Quercus* forest shows odd pattern with negative correlation of NDVI with the precipitation of same month. In case of 2 month lag precipitation relation with NDVI, all forest types have shown unimodal relation with highest NDVI around 500 to 700 mm in two months. Precipitation here does not seem to be limiting factor as surplus precipitation has even done deleterious effect to the NDVI. In case of *Quercus* forest, clear negative trend of decreasing NDVI on increasing precipitation is seen and cause remains unidentified.

Among five forest types *Picea-Tsuga* forest is found to be of highest productivity, which is followed by *Quercus* forest, *Larix, Pinus wallichiana* and *Betula-Abies* forest. The mean NDVI difference as calculated of 9-year period is significantly different among all forest types, except with *Pinus wallichiana* and *Larix.* They have similar NDVI values implying similar productivity status. *Betula-Abies* forest shows least average NDVI values among all the forests studied. These variations have affinity with altitude, physiogrpahy, species association and anthropogenic influences to the forest.

References

Agrawal S. 2003. *Principles of Remote Sensing*. In Satellite Remote Sensing and GIS Applications in Agricultural Meteorology. Proceedings of the Training Workshop 7-11 July, 2003, Dehra Dun, India. Eds. MVK Sivakumar, PS Roy, K Harmsen and SK. Saha. World Meteorological Organisation 7bis, Avenue de la Paix 1211 Geneva 2, Switzerland.

Ahl DE, ST Gower, SN Burrows, NV Shabanov, RB Myneni and Y Knyazikhin. 2006. Monitoring spring canopy phenology of a deciduous broadleaf forest using MODIS. *Remote Sensing of Environment* 104:88-95.

All J. 2009. GIS/Remote sensing techniques for resource management and biodiversity protection in mountainous regions. *Botanica Orientalis* 6:93-99.

Aranha JT, HF Viana and R Rodrigues. 2008. Vegetation classification and quantification by satellite image processing, A case study in North Portugal. *Bioenergy: Challenges and Opportunities, International Conference and Exhibition on Bioenergy,* April 6th – 9th 2008, Universidade do Minho, Guimarães, Portugal.

Atkinson PM and P Aplin. 2004. Spatial variation in land cover and choice of spatial resolution for remote sensing. *International Journal of Remote Sensing*. 25(18):3687–3702.

Baidya NG, DR Bhuju, P Kandel. 2009. Land use change in buffer zone of Chitwan National Park, Nepal between 1978 and 1999. *Ecoprint* 16:79-86.

Bajracharya B and K Uddin. 2010. Mapping land cover and understanding its dynamics in Sagarmatha National Park and Buffer Zone. In *Contemporary Research in Sagarmatha (Mt. Everest) Region, Nepal*. Eds. PK Jha and IP Khanal, Nepal Academy of Science and Technology, Khumaltar, Lalitpur P 37-44

Baldi G, MD Nosetto, R Aragón, F. Aversa, JF Paruelo, and EG Jobbágy . 2008. Long-term satellite NDVI data sets; evaluating their ability to detect ecosystem functional changes in South America. *Sensors* 8:5397-5425.

Boelman NT, M Stieglit, HM Rueth, M Sommerkorn, KL Griffin, GR Shaver, JA Gamon. 2003. Response of NDVI, biomass, and ecosystem gas exchange to long-term warming and fertilization in wet sedge tundra. *Oecologia* 135:414–421.

Brook JR, HR Barnard, R Coulombe, JJ McDonnel. 2010. Ecohydrologic separation of water between trees and streams in a Mediterranean climate. *Nature Geoscience* 3: 100-104.

Brown J F, TR Loveland, JW Merchant, BC Reed, & DO Ohlen. 1993. Using multisource data in global land-cover characterization: Concepts, requirements, and methods. *Photogrammetric Engineering and Remote Sensing* 59: 977–987.

Casals-Carrasco P, S Kubo and B Babu Madhavan. 2000. Application of spectral mixture analysis for terrain evaluation studies. *International journal of Remote Sensing*. 21(16): 3039–3055

Chu D, L Lu and T Zhang. 2007. Sensitivity of normalized difference vegetation index (NDVI) to seasonal and interannual climate conditions in the Lhasa area, Tibetan Plateau, China. *Arctic, Antarctic, and Alpine Research* 39(4):635-641.

Cihlar J. 2000. Land cover mapping of large areas from satellites: status and research priorities; *International Journal of Remote Sensing*. 21(6 & 7): 1093–1114.

Cohen WB and Justice C. 1999. Validating MODIS terrestrial ecology products: linking in situ and satellite measurements; *Remote Sensing of Environment* 70:1–3.

Dawson TP, PRJ North. SE Plummer, PJ Curran. 2003. Forest ecosystem chlorophyll content: implications for remotely sensed estimates of net primary productivity. *International Journal of Remote Sensing* 24 (3):611-617.

Delbart N, TT Le, L Kergoat, and V Fedotova. 2006. Remote sensing of spring phenology in boreal regions: A free of snow-effect method using NOAA-AVHRR and SPOT-VGT data (1982-2004). *Remote Sensing Environment* 101: 52-62.

DHM. 2010. *Rainfall and Temperature Data of Gorkha Station from 2000 to 2009*. Department of Hydrology and Meteorology, Ministry of Environment, Government of Nepal, Babarmahal Kathmandu.

Dong J, RK Kaufmann, RB Myneni, CJ Tucker, PE Kauppic, J Liskid, W Buermann, V Alexeyev and MK Hughes. 2003. Remote sensing estimates of boreal and temperate forest woody biomass: carbon pools, sources, and sinks. *Remote Sensing of Environment* 84:393–410.

Evans D L, Z Zhu and K Winterberger. 1993. Mapping forest distributions with AVHRR data. *World Resource Review* 5:66– 71.

FAO. 2000. Land Cover classification systems (LCCS): Classification Concept and User Manual. Food and Agriculture Organization.

Foody GM. 2002. Status of land cover classification accuracy assessment. *Remote Sensing of Environment* 80:185-201.

Foody GM, A Muslim, and PM Atkinson. 2005. Super-resolution mapping of the waterline from remotely sensed data. *International Journal of Remote Sensing.* 26(24):5381–5392

GLCF 2011. online. Global land cover facility. University of Merryland. www.glcf.umd.edu, assessed October 16, 2011

Gómez-Mendoza L, L Galicia, ML Cuevas-Fernández, V. Magaña, G. Gómez and JL Palacio-Prieto. 2008. Assessing onset and length of greening period in six vegetation types in Oaxaca, Mexico using NDVI-precipitation relationships. *International Journal of Biometerology* 52:511–520.

Holme AM, DG Burnside and AA Mitchell. 1987. The development of a system for monitoring trend in range condition in the arid shrublands of Western Australia. *Australian Rangeland Journal* 9:14-20.

Horton JH and RH Hawkins. 1965. Flow path of rain from soil surface to water table. *Soil Science* 100:377-383.

Huete A, K Didan, T Miura, EP Rodriguez, X Gao, and LG Ferrerira. 2002. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment* 83:195-213.

Iichii K, A Kawabata and Y Yamaguchi. 2002. Global correlation analysis for NDVI and climatic variables and NDVI trends: 1982–1990. *International Journal of Remote Sensing* 23(18): 3873–3878.

IJRS. 1986. Editorial of International Journal of Remote Sensing. *International Journal of Remote Sensing* 7: 1395.

Ingram CT and TP Dawson. 2005. Climate change impact and vegetation response on Island of Madagascar. *Philosophical Transaction of the Royal Society A* 363:55-9.

Jeganathan JD and PM Atkinson. 2009. Predicting phenology using time series Remote Sensing data. Initial results for the Indian forests. *Seminar on Spatial Information Retrieval, Analysis, Reasoning and Modelling*. 18th-20th March 2009. ISI-DRTC, Bangalore, India 149.

Justice CO, E Vermote, JRG Townshend. 1998. The Moderate Resolution Imaging Spectroradiometer MODIS; land remote sensing for global change research. *IEEE Trans Geosci. Remote Sensing* 36: 1228-1249.

Kale M.P, S Singh and PS Roy. 2002. Biomass and productivity estimation using aerospace data and Geographic Information System. *Tropical Ecology* 43(1): 123-136.

Kawabata A, K Ichii, and Y. Yamaguchi. 2001. Global monitoring of the interannual changes in vegetation activities using NDVI and its relationships to temperature and precipitation. *International Journal of Remote Sensing* 22:1377–1382.

Kawamura K, A Tsyoshi, O Watanabe, H Hagesawa FP Zhang, H Yokota, S Wang. 2003. Estimation of Aboveground Biomass in Xillingol Steppe, Inner Mongolia Using NOAA/ NDVI. *Grassland Science* 49-1.

Kinyanjui MJ. 2010. NDVI-based vegetation monitoring in Mau forest complex, Kenya. *African Journal of Ecology*. 49:165-174.

Lillesand TM and RW Kiefer. 2000. *Remote sensing and image interpretation*, 4th ed. New York: John Wiley and Sons.

Long W, S Srihann. 2004. *Land cover classification of SSC image: unsupervised and supervised classification using ERDAS Imagine*; Proceeding of Geoscience and Remote Sensing Symposium, 2004 IGARSS '04.

Loveland TR, JW Merchant, DO Ohlen, & JF Brown. 1991. Development of a land-cover characteristics database for the conterminous U.S. *Photogrammetric Engineering and Remote Sensing* 57(11):1453– 1463.

MacEachren J, SJ Shah , TB Shrestha, BD Pande, NP Bhusal. 1995. *Prospects of Tourism in Manaslu, A Reconnaisance Survey*. IUCN- The World Conservation Union, Kathmandu Nepal

Mather JR and G Oshioka. 1968. The role of climate in the distribution of vegetation. *Ann Assoc Am Geogr* 58:29–41.

Mingjun D, Y Zhang, L Liu, W Zhang, Z Wang and W Bai. 2007. The relationship between NDVI and precipitation on the Tibetan Plateau. *Journal of Geographical Sciences* 259-268 .

MENRIS. 2010. online. http://geoportal.icimod.org/Downloads/. MENRIS Mountain Geoportal. Accessed 2010, May 5.

MODIS. 2011. Online. http://modis-land.gsfc.nasa.gov/vi.html. NASA. Accessed 2011 March 19.

Navalgund RR, V Jayaraman and PS Roy. 2007. Remote sensing applications: An overview. *Current Science* 93(12):1747-1766.

NASA. 2010. online . http://earthobservatory. nasa.gov/ Features/Measuring Vegetation/000 measuring_ vegetation_2.php. *National Aeronautical and space Administration, USA*, Assessed 2010 December 19.

NOAA . 2003. Online. What is NDVI? http://www.csc.noaa.gov/crs/definitions/NDVI.html. National Oceanic and Atmospheric Administration

NTNC. 1998. *Project proposal for Manaslu Conservation Area*. National Trust for Nature

Conservation. Nepal.

NTNC. 2011. online. http://www.ntnc.org.np/project/manaslu-conservation-area-project; Manaslu Conservation Area Project, National Trust for Nature Conservation, Nepal. Assessed july 4 2011.

Panda BC. 2005. *Remote Sensing Principles and Application*, First edition. Viva Books private Limited. India. 134-136.

Paudel KP, P Anderson. 2010. Assessing rangeland degradation using multi temporal satellite images and grazing pressure surface model in Upper Mustang, Trans Himalaya, Nepal. *Remote Sensing of Environment* 114:1845–1855.

Piao S, J Fang, L Zhou, LK Tan and S Tao. 2007. Changes in biomass carbon stocks in China's grasslands between 1982 and 1999. *Global Biogeochemical Cycles*, 21.

Pradhan S. 2006. *Monitoring vegetation changes with NDVI trends for effective response to food insecurity*. Map Asia 2006, Fifth Annual International Conference and Exhibition on geographical information technology and applications, 29 August to 1 September 2006, Bangkok, Thailand.

Prasad VK, E Anuradha, KVS Badrinath. 2005. Climatic controls of vegetation vigor in four contrasting forest type of India- evaluation from National Oceanic and Atmospheric Administration Advanced Very High Resolution radiometer datasets (1990-2002). *International Journal of Biometerology* 50:6-16.

Prince SD. 1991. A model of regional primary production for use with coarse resolution satellite data. *International Journal of Remote Sensing* 12:1313– 1330.

Richard Y and I Poccard. 1998. A statistical study of NDVI sensitivity to seasonal and interannual rainfall variations in Southern Africa. *International Journal of Remote Sensing* 19: 2907–2920.

Rundquist BC and JA Harrington Jr. 2000. The Effects of Climatic Factors on Vegetation Dynamics of Tallgrass and Shortgrass Cover. *Geocarto International* 15(3):33-38.

Rundquist BC, JA Harrington Jr. and DG Goodin. 2000. Mesoscale satellite bioclimatology. *Prof Geogr* 52:331–344.

Running SW and RR Nemani. 1988. Relating seasonal patterns of the AVHRR vegetation index to simulated photosynthesis and transpiration of forest in different climates. *Remote Sensing of Environment* 24:347– 367.

Sabins FF. 1978. *Remote sensing principles and interpretation*, first edition. W. H. Freeman and Company, USA.

Sharma BD, J Clevers R De Graaf and NR Chapagain. 2003. Assessing the land cover situation in Surkhang, Upper Mustang, Nepal, using an ASTER image. *Himalayan Journal of Sciences* 1(2): 93-98.

Sokal RR. 1974. Classification: Purposes, Principles, Progress, Prospects. *Science*. 185 (4157):1115-1123.

Sriharan S, D Guest and L Martin. 2004. *Analysis of Land Cover classes using unsupervised and supervised classification of Stennis Space center (SSC) image*. NASA Faculty Fellowship Program 2004, Stennis Space Center.

Townshend JRG and CJ Tucker. 1984. Objective assessment of AVHRR data for land cover mapping. *International Journal of Remote Sensing* 5: 497-504.

Tucker CJ and PJ Sellers. 1986. Satellite remote sensing of primary productivity. *International Journal of Remote Sensing* 7:1395– 1416.

Tucker CJ, DA Slayback, JE Pinzon, SO Los, RB Myneni and MG Taylor. 2001. Higher northern latitude normalized difference vegetation index and growing season trends from 1982 to 1999. *International Journal of Biometeorology* 45:184-190.

NASA 2011. Online. http://earthobservatory.nasa.gov/Features/LandCover/. Accessed 2011 October 15.

Wang J, PM Rich and KP Price. 2003. Temporal responses of NDVI to precipitation and temperature in the central Great Plains, USA. *International Journal of Remote Sensing* 24(11): 2345–2364.

Wang J, PM Rich, KP Price and WD Kettle. 2005. Relations between NDVI, Grassland Production, and Crop Yield in the Central Great Plains. *Geocarto International* 20(3):5-11.

Wang Q, J Tenhunen, N Dinh, M Reichsteina, T Vesalab and P Keronen. 2004. Similarities in ground- and satellite-based NDVI time series and their relationship to physiological activity of a Scots pine forest in Finland. *Remote Sensing of Environment.* 93:225–237.

White MA, RR Nemani, PE Thornton and SW Running. 2002. Satellite evidence of phenological differences between urbanized and rural areas of the eastern United States deciduous broadleaf forest. *Ecosystems* 5:260-273.

Wijaya A, S Kusnadi, R Gloaguen and H Heilmeier. 2010. Improved strategy for estimating stem volume and forest biomass using moderate resolution remote sensing data and GIS. *Journal of Forestry Research* 21(1):1-12.

Xiao X, SB Frokling, C Li, JY Babu, W Salas and B Moore. 2006. Mapping paddy rice agriculture in South and Southeast Asia using multi-temporal MODIS images. *Remote Sensing of Environment* 100:95 – 113.

Xie Y, Z Sha and M Yu. 2008. Remote sensing imagery in vegetation mapping: a review, *Journal of Plant Ecology* 1(1): 9–23.

Zomer RJ, SL Ustin and CC Carpenter. 2001. Land cover change along tropical and subtropical riparian corridors within the Makalu Barun National Park and Conservation Area, Nepal. *Mountain Research and Development* 21(2):175-183.

Appendices

Appendix 1

Sample of training data (ground control points, GCPs) collection sheet.

1		GPS			UTM Coordinates		Date and			Aspect		
2	GCP#	Error	Lat	Long	Easting	Northing	Time	Elevation	Picture #s	Asp Dir	Asp Deg	Slope
102	100	16	28.35654823	84.88152347	293350	3138507	16-DEC-09 10:08:53	1340	35	NE	60	65
103	101	7	28.35837817	84.88904402	293111	3138714	16-DEC-09 10:20:39	1349	45	SE	160	2
104	102	15	28.35945826	84.88870029	293079	3138834	16-DEC-09 10:27:32	1366	55			
105	103	17	28.36016469	84.88885559	293095	3138912	16-DEC-09 10.53.42	1384	66			
106	104	14	28.36348803	84.88720846	292940	3139283	16-DEC-09 11:00:18	1580	76	NE	70	20
107	105	5	28.36473249	84.88703957	292925	3139427	16-DEC-09 11:07:02	1531				
108	106	5	28.36569691	84.88730343	292964	3139528	16-DEC-09 11:12:20	1507	86			
109	107	5	28.36619311	84.88830700	293054	3139614	16-DEC-09 11.24.09	1481	96	W	260	25

1		Landcover	Upper Canopy			Middle Canopy					Ground Cover (%)			
2	GCP#	Code	Closure	Ht.(m)	DBH (c	Closure	Ht.(m)	DBH(cm	Herb	Shrub	Litter	Ice	Rock	Water
102	100	CG				2	3	5	50					
103	101	AG							10		20		20	
104	102	S							25				60	
105	103	AG							10		35		20	
106	104	AG				10	3	5	10		40		30	
107	105	S									10		60	
108	106	BR												100
109	107	LSTD/AG				10	2	5	85				5	

1		(%)		Landcover codes +75 m				Upper Canopy				Middle Canopy					Ground			Other Comments and disturbances					
2	GCP#	Water	Soil	North	East	South	West	Sp 1	Sp 2	Sp3	Other Sp	Species 1	Sp2	Sp 3	Oth Sp	Sp1	Species 2	Species 3	Other Species	Fire	Grazing	Timber	Fodde	Mining/Excav	Animals
02	100		50	H2O	H2O	CG	CG					Cannabis				G	Art	Eu	Lab,Bou,Ana						
03	101		50	S	H2O	FP	CG									Com	Urt	Ag	Fern,Eu						
04	102		20	S	AG	S	AG									Veges	Urt	Corn							
05	103		35	H2O	H2O	S	CG									Com	Clv	Art	Fern,Eu						
06	104		20	S	H2O	LSTD	CG					Euph	Banana			Urt	Com	Fern	Clv, G				5		
07	105		30	S	FP/AG	AG/S	S/CG																		
08	106	100		H2O	S/AG	H2O	CT/CG																		
09	107		10	AG	CG	CG	AG/H2O					Arun	Meaz			G	Art	Ana				4	5		

1							
2	GCP#	Animals	Slumps/S	Insect Fe	Dead Ti	Disease	Drough	Other Comments
102	100							trail cut into cliff,above flood plain/river,river is very wide to east
103	101							southern edge of agriculture,flood plain to S and small village to N,on powerline
104	102							Salleri village,small AG surrounding the village,very nice stone wall>100m,11 blds,2 new foundations in progress
105	103							small Ag field/cliff to FP below
106	104							Ag fields south of settlement,powerline
107	105							
108	106							Bridge over Budigandaki main river,looks like it collapsed built/rebuilt in 2009 but pieces all look older(stone date)
109	107							fields surrounding disturbed pixel

Appendix 2

Monthly NDVI data of each forest type:

Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Month	*Betula-Abies*								
January	0.156	0.085	0.163	0.148	0.094	0.129	0.229	0.234	0.168
February	0.083	0.144	0.039	0.021	0.097	0.022	0.243	0.034	0.065
March	0.071	0.079	0.035	0.047	0.256	0.053	0.028	0.050	0.091
April	0.248	0.230	0.091	0.203	0.307	0.185	0.147	0.272	0.216
May	0.300	0.374	0.349	0.347	0.274	0.347	0.293	0.343	0.328
June	0.278	0.524	0.470	0.356	0.474	0.423	0.461	0.549	0.423
July	0.404	0.204	0.561	0.444	0.281	0.358	0.477	0.412	0.330
August	0.499	0.314	0.320	0.364	0.532	0.439	0.537	0.476	0.445
September	0.433	0.441	0.348	0.459	0.412	0.422	0.436	0.465	0.398
October	0.321	0.322	0.305	0.322	0.179	0.260	0.345	0.329	0.312
November	0.296	0.302	0.223	0.310	0.294	0.226	0.293	0.301	0.274
December	0.302	0.292	0.252	0.094	0.274	0.255	0.252	0.260	0.275
Larix									
January	0.487	0.583	0.290	0.514	0.545	0.430	0.583	0.540	0.410
February	0.454	0.560	0.292	0.178	0.588	0.437	0.638	0.378	0.565
March	0.495	0.515	0.486	0.580	0.585	0.716	0.335	0.379	0.543
April	0.595	0.603	0.644	0.622	0.616	0.624	0.581	0.609	0.610
May	0.735	0.669	0.705	0.682	0.687	0.711	0.673	0.603	0.622
June	0.534	0.766	0.788	0.668	0.787	0.553	0.735	0.743	0.750
July	0.795	0.639	0.846	0.891	0.762	0.684	0.792	0.666	0.729
August	0.729	0.731	0.856	0.655	0.746	0.655	0.837	0.827	0.781
September	0.795	0.792	0.781	0.806	0.794	0.798	0.796	0.807	0.855
October	0.696	0.638	0.738	0.635	0.637	0.699	0.648	0.712	0.641
November	0.589	0.506	0.502	0.518	0.538	0.618	0.583	0.684	0.527
December	0.410	0.320	0.476	0.577	0.556	0.542	0.490	0.484	0.408
Pinus wallichiana									
January	0.572	0.609	0.515	0.590	0.669	0.436	0.596	0.570	0.591
February	0.487	0.518	0.383	0.267	0.597	0.508	0.602	0.427	0.593
March	0.602	0.562	0.574	0.598	0.552	0.596	0.445	0.574	0.553
April	0.555	0.544	0.551	0.592	0.577	0.592	0.531	0.505	0.565
May	0.640	0.674	0.685	0.719	0.655	0.651	0.668	0.743	0.693
June	0.567	0.764	0.778	0.668	0.794	0.661	0.729	0.731	0.702
July	0.819	0.681	0.775	0.842	0.658	0.745	0.812	0.719	0.636
August	0.833	0.701	0.667	0.686	0.740	0.599	0.855	0.750	0.747
September	0.784	0.815	0.766	0.828	0.804	0.790	0.789	0.816	0.777
October	0.663	0.685	0.686	0.706	0.698	0.738	0.643	0.709	0.693
November	0.605	0.625	0.562	0.601	0.615	0.601	0.553	0.629	0.605

December	0.537	0.562	0.581	0.525	0.566	0.459	0.563	0.578	0.571
Quercus									
January	0.686	0.767	0.666	0.731	0.749	0.525	0.708	0.705	0.636
February	0.678	0.714	0.682	0.676	0.753	0.568	0.735	0.622	0.675
March	0.661	0.706	0.715	0.718	0.700	0.746	0.706	0.692	0.714
April	0.701	0.717	0.705	0.690	0.711	0.702	0.717	0.681	0.687
May	0.709	0.677	0.711	0.710	0.706	0.692	0.587	0.683	0.685
June	0.496	0.796	0.641	0.426	0.728	0.617	0.512	0.664	0.685
July	0.774	0.176	0.628	0.862	0.199	0.487	0.823	0.260	0.653
August	0.427	0.390	0.585	0.404	0.389	0.528	0.854	0.665	0.508
September	0.845	0.869	0.816	0.828	0.477	0.840	0.803	0.830	0.801
October	0.769	0.772	0.739	0.794	0.763	0.787	0.759	0.795	0.749
November	0.738	0.769	0.781	0.746	0.750	0.771	0.727	0.751	0.699
December	0.716	0.740	0.761	0.654	0.720	0.770	0.693	0.755	0.687
Picea-Tsuga									
January	0.695	0.772	0.785	0.767	0.690	0.691	0.539	0.618	0.698
February	0.759	0.730	0.820	0.731	0.736	0.851	0.691	0.728	0.783
March	0.737	0.743	0.778	0.795	0.697	0.805	0.605	0.805	0.725
April	0.725	0.756	0.748	0.806	0.751	0.761	0.749	0.757	0.718
May	0.855	0.808	0.804	0.822	0.644	0.801	0.753	0.845	0.785
June	0.726	0.706	0.837	0.678	0.774	0.700	0.673	0.734	0.764
July	0.739	0.647	0.839	0.892	0.707	0.706	0.818	0.628	0.749
August	0.875	0.740	0.670	0.508	0.800	0.756	0.886	0.798	0.701
September	0.839	0.861	0.817	0.839	0.843	0.809	0.834	0.846	0.854
October	0.819	0.801	0.792	0.780	0.808	0.824	0.735	0.797	0.754
November	0.668	0.729	0.755	0.686	0.624	0.723	0.557	0.742	0.667
December	0.515	0.646	0.587	0.738	0.530	0.609	0.623	0.642	0.558

Appendix 3

Monthly Rainfall and Temperature Data

Monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	14	14	27.1	105.2	251	432	282	474	154	0	0	0
2001	7.5	34.2	3	98.5	241	360	410	528	179	2.5	9	0
2002	48	33.7	13	190	214	205	498	333	175	16.2	18	0
2003	34	64.2	57	46.4	111	347	567	334	147	3	0	18
2004	27	2.5	0	143	133	364	411	275	216	39.3	2	0
2005	50	4.8	52	106	207	104	256	294	106	98.5	0	0
2006	0	0	21	67.6	125	228	294	217	129	1.8	2.8	29
2007	0	107.1	44	84.5	101	489	363	176	353	37.6	7.3	0
2008	0	0	30	145	154	441	209	406	88	9.4	0	0

Monthly average temperature (^oC)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	13.29	16.33	18.06	22.02	24.77	24.59	25.43	25.53	24.63	21.71	16.78	13.50
2002	12.60	16.10	19.95	22.90	24.25	26.55	26.45	26.45	24.95	22.25	17.90	14.10
2003	12.35	15.30	19.05	24.00	26.13	27.30	26.95	27.30	25.95	23.05	18.30	13.65
2004	12.35	15.90	21.15	22.33	25.98	21.60	21.05	22.15	20.95	17.00	12.60	10.90
2005	10.55	16.83	20.98	24.57	26.05	27.75	27.25	27.35	27.15	22.85	17.75	13.80
2006	13.80	19.70	21.25	24.40	26.80	27.05	27.80	27.55	26.10	23.90	19.20	14.90
2007	13.60	15.65	20.15	25.10	26.75	26.95	26.75	27.15	25.85	23.60	18.40	13.95
2008	13.45	15.50	21.55	24.25	25.20	26.60	27.25	26.90	26.20	23.35	19.25	16.00

Source: DHM, 2011

Appendix 4

Description of land covers classes

Land cover types	Descriptions
Forest:	This cover class is forested land with more than 10% of canopy coverage with canopy plants having height more than 5 meter.
Shrubland/Degraded forest	This class includes only shrubs or shrubs and trees interspersed, with less than 10% canopy and plants having height less than 5 meter.
Agriculture & Settlement	This cover class includes village and community settlements as well as adjoining crop fields and tree stands. There are some clustered settlements and crop field around and some scattered houses within the crop field in Manaslu Conservation Area.
Bare soil	This class includes land slide eroded bare lands and vegetation removed land where bare soil is exposed.
Grassland	This class mostly includes alpine treeless pastures. Low altitude grasslands and pastures also fall in this category.
Riparian	This is water related cover class. It includes rivers, rivulets, glaciers, glacial lakes and snow cover.
Boulder and Grass	This cover class is rocky terrain and boulder land with very little grasses and grass like vegetation interspersed.