Chapter-6

Climate Change and Vegetation

6.1 Introduction
Vegetation is an indicator of climatic conditions. The climatic conditions of an area can be easily understood using the characteristics of vegetation. It is so because climate determines the distributional patterns, structure, growth, abundance, diversity, density, richness, survival of vegetation and its ecology. It also regulates natural ecosystems in a variety of ways. On the other hand, it also moderates the climatic conditions. Several studies about interlinkages of climate and vegetation have revealed that certain vegetation types are associated with particular type of climate (Gopalkrishnan et al., 2011). However, these interlinkages are very complex and still cannot be clearly comprehended.

Climate change is now widely accepted phenomenon (IPCC, 2007a) influencing vegetation characteristics in number of ways (Baker and Moseley, 2007; Bharali and Khan, 2011 and IPCC, 2007b). As the climate changes, all vegetation types experience a variety of changes, including vegetation stress in those areas where climate becomes too stressful, and prospering where climate becomes salubrious. The climate change can induce the vegetation to become either a source of additional CO$_2$ leading to higher rates of warming or a sink for CO$_2$ leading to lower rates of warming. However, the actual direction of impacts of climate change on vegetation is still not known and understood (www.epa.gov).

The various inferred effects of climate change on vegetation are diverse such as change in carbon stock of vegetation, timing of phenological events of plants, species abundance, richness and range, altitudinal and latitudinal shifts of habitat/vegetation, increase of photosynthetic activities of vegetation etc. The rate of adaptation and responses of different vegetation types and species are different to climate change. Thus, different vegetation and species adjust to changing climate at different rates and by different process. The high altitudinal and latitudinal ecosystems and vegetation are particularly at higher risk of changes and modifications and further to extinction because of their higher levels of sensitivity to changing climate (Panigrahy et al., 2010 and Bharti et al., 2011a). Climate change can cause variety of changes to vegetation at high altitudes like upward shift. Species in transition zones (subalpine and alpine) are especially vulnerable to climate change, as they have limited scope to move further.
Peter and Darling (1985) outlined two basic hypotheses concerning potential impacts of climatic changes on vegetation. First hypothesis states that the species in the northern hemisphere would move poleward under proposed climate change scenarios in direct response of increasing temperature. The other hypothesis states that increase in temperature would move the species up-slope in a linear manner, where each successive altitudinal range would be replaced by the species habitat occupying the zone directly below. The tropical vegetation would occupy the altitudes of temperate vegetation, the temperate vegetation of sub-alpine vegetation, the sub-alpine vegetation of alpine vegetation and alpine vegetation would colonize the newly exposed altitudes from glacier retreats. Several studies such as Mizuno (2005) confirms second hypothesis that plant communities advance in response to the retreat of glaciers in African mountains. Rapid glacial retreat has been accompanied by rapid colonization by plants.

Many other studies also reveal similar relationships of the changing vegetation in relation to climate change. Earlier flowering of plants and increase of growing season by about 1 to 4 days/decade during the last 40 years in the Northern Hemisphere, especially at higher latitudes was reported by IPCC (2002). Vegetations and treelines have shifted in different parts of world at different rates (Song et al., 2005). Dubey et al. (2003) estimated upslope shift of pine as 19 and 14 m/decade on southern and northern slopes respectively in Parbati valley of Himachal Pradesh. Similarly, the treeline was estimated to shift upslope by about 300 m during 1960-2004 in NDNP, Uttarakhand by Panigrahy et al. (2010). The study was however heavily criticized and rejected by Bharti et al. (2011a). Contrary to this, they suggested that vegetation and timberline has only marginally changed. Sitko and Troll (2008) concluded altitudinal shift of about 80 m in Ukrainian Carpathians. It has been noted that the boreal forests are expanding north at a rate equal to about 100 to 150 km per °C (IPCC, 2002).

The increasing vegetation activities and growth have been correlated with changing climatic conditions in China and Eurasia by Shilong et al. (2005 and 2011). Whereas, the growth of treerings of *Betula Utilis* using dendrochronology study and analysis of climatic data showed highly positive correlation (Bhattacharya et al., 2006). It was further inferred that vegetation respond to changing climates. Bharti et al. (2011b) revealed that shifting of vegetation zones upslope as a result of climate change in NDNP. Rana et al. (2010) reported unusual composition of the plant species towards ablation zone of Tipra glacier, VoFNP in Garhwal Himalaya. The pioneer species have colonized the areas beyond the snout positions. Few species are even located closer to snow line.
Changing vegetations in natural and near natural areas can serve as the proxy to understand the extent of climate change in absence of instrumental records of climatic parameters (precipitation and temperature). Alternatively, changing vegetation over the period of time can also be studied as an influence of climate change. Future changes of vegetation due to climate change are important key questions for scientists in order to understand the future responses of vegetation. These can be studied on the basis of the historical relations of both.

There are two types of method to study the relationships of vegetation and climate change viz. field based and satellite image based. Field based methods include dendrochronology (that deals with tree rings and reconstruct the climatic history) and field investigations of species composition, density, richness, abundance, and colonization etc. over a period of time. The dendrochronology deals with reconstruction of the climatic history on the basis of analysis of tree rings. The satellite image based studies use multi temporal satellite images together with ground checks to study greening, specie composition, density, richness, abundance and colonization etc. Present study deals primarily with second method.

6.2 Data Sources
Present chapter mainly uses secondary and primary data including DEMs, satellite images and field investigations for assessing the historical changes of vegetation in relation to climate change over a period of time. The Landsat MSS, TM and ETM+ satellite images have been used (Table 6.1) for deriving the information of vegetation over the years. The satellite images were obtained from USGS-glovis. Season of the satellite images is very important for change detection studies of vegetation, since it determines the state of health of vegetation. Important consideration while selecting the images for change detection studies is that they should be of same season (preferably of same dates). Vegetation is photosynthetically more active during monsoon season, thus can be best studied. However, heavy over cast hinders acquisition of cloud free satellite images. It renders the studies of vegetation in monsoon season impossible using the satellite images. Therefore, satellite images of pre-monsoon or post-monsoon should be used. Cloud free satellite images for longer duration were not available for pre-monsoon season and on the other hand, some very good satellite images of post-monsoon month (October and November) were available. Hence, images of close to second week of October and first week of November were selected for the present study. Although, vegetation is less active during this part of the year especially in the month of November. Thus, higher accuracy of information may not be achieved. Also, grasslands of higher altitudes (alpine) partially turn to bareland during this month. The images of winters for the studies of vegetation in high altitude
regions should be avoided as trees release their leaves and grasslands turn to bareland. As a result, actual state of vegetation is not captured in high altitude regions during winters.

<table>
<thead>
<tr>
<th>Satellites</th>
<th>Sensors</th>
<th>Path/Row</th>
<th>Acquired Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 5</td>
<td>TM</td>
<td>145/39</td>
<td>6-11-2010</td>
</tr>
<tr>
<td>Landsat 7</td>
<td>ETM+</td>
<td>145/39</td>
<td>15-10-1999</td>
</tr>
<tr>
<td>Landsat 3</td>
<td>MSS</td>
<td>145/39</td>
<td>26-10-1979</td>
</tr>
<tr>
<td>ASTER GDEM2</td>
<td>--</td>
<td>145/39</td>
<td>17-10-2011*</td>
</tr>
</tbody>
</table>

*Release date

Several field visits were made to different parts of NDBR in order to collect the ground information of different vegetation zones. Bhundyar Ganga valley, VoF, Amrit Ganga valley, Upper Alaknanda valley, Lower Sarasvati valley, Dhauliganga valley, NDNP, Dunagiri valley, Girithi Ganga valley and Lapthal areas have been visited. Extensive photography of vegetation has been done for the reference and post-analysis ground verification. The photographs have been adjusted to altitude, latitude and longitude informations obtained from Garmin etrex vista GPS. Besides, some published research papers about forests and vegetation of NDBR have been consulted.

6.3 Methods
Since all the satellite images obtained were in raw form, these needed some basic but necessary corrections. The correction methods vary from image to image and application to application. No correction method is final and best suited for all images and applications. Satellite images having different land cover classes may need different types of corrections depending on the research questions. Also, the satellite images of mountain area need to be more carefully corrected than that of plains due to higher radiometric and topographic variations. Ecosystems with high altitudinal range are quite sensitive to seasonal changes. Therefore, the season, altitude of sun, amount of rainfall and snowfall during the year for which the satellite image was acquired and used are very important. This is especially important for change detection studies in mountain areas. Change detection of images of different seasons will not lead to desired results needed for the studies of influence of changing climate on vegetation. Therefore, the images of same months should be used so that reflectance or digital numbers (DN) are identical and near-accurate results may be obtained. Keeping all these factors in mind, Bruce and Hilbert (2004) suggested following image corrections that have been also applied to the satellite images used for present study (Figure 6.1).
6.3.1 Image Correction and Analysis

6.3.2 Geometric and Ortho-rectification

The acquired satellite images were already projected to UTM projection system. All the images showed good geometric fit, thus no further geometric rectification was attempted. However, ortho-rectification was done. It corrects the geometric distortion of satellite images caused by camera/sensor orientation, topographic/terrain displacement etc. It removes the variations of scale in different parts of images and corrects as to the nadir point. It is applied to satellite images in combination with DEM of same area. The spatial resolutions of satellite images and DEM should be same. The resulted images are planimetrically true that represent ground objects in their real world and X and Y positions. Orthorectification is highly recommended for the images of mountain areas, where high degree of accuracy is required. Therefore, orthorectification was done for all the satellite images (Landsat) used in this study. The ASTER
GDEM2 obtained from LPDAAC was used for the orthorectification with the help of ERDAS Imagine 9.2.

### 6.3.3 Radiometric Correction and Relative Radiometric Normalisation (atmospheric corrections)

In satellite images, the brightness values (DN) for any object are influenced by a range of factors including changes in scene illumination, atmospheric conditions (absorption and scattering), response characteristics and viewing geometry of instrument. Therefore, it is necessary to correct satellite images for radiometric errors to assess actual changes over a period and surface as revealed by changes in the spectral reflectance of multi temporal satellite images. However, the correction of these factors depends on the applications and objectives of study (Bruce and Hilbert, 2004).

Two approaches viz. absolute and relative corrections have been developed for radiometric variations. The absolute correction approach completely removes the varying radiometric errors. It produces an image with absolute reflectance value for each pixel free from atmospheric influences. It requires information of atmospheric properties at the time of image acquisition for atmospheric correction and sensor calibration. The required informations are available with metadata file supplied with satellite images. This approach is mainly used for studies concerned with only one satellite image.

However, most of the studies (especially change detection) require more than one image. Thus, absolute correction alone is not enough. Dark Object Subtraction (DOS) is one of the important absolute radiometric correction methods that removes the influence of atmosphere and produces absolute reflectance image. The technique assumes uniform atmospheric condition over the image area, which can be easily corrected. It requires the estimation of atmospheric effects over image (Bruce and Hilbert, 2004). The effect of atmosphere can be easily estimated by examining the area that should have lowest reflectance such as deep water and shadow. Ideally such areas should have reflectance value close to zero, but if it exceeds that can be attributed to atmospheric influence i.e. haze. In such cases, the actual value of dark pixel is subtracted from the image in order to remove this error. DOS method was combined with model of DN to reflectance.

The relative approach, which is also known as relative radiometric normalisation (RRN), is widely used for change detection studies. It corrects/matches the radiometry of all images to the
radiometric conditions of a reference image. Many relative radiometric correction methods have been developed viz. statistical adjustment, histogram matching and linear regression normalisation (Sotomayor, 2002). RRN is used for studies that require more than one image of one time period (especially that requires mosaics) or multi temporal images. In this study, histogram matching has been applied to calibrate the reflectance of all the images used in present study to the reference image. The RRN technique was applied after all the other corrections.

6.3.4 Conversion of Digital Numbers (DN) to Radiance and Radiance to Reflectance

Other important process in radiometric correction is conversion of DN values to top of atmosphere (TOA) reflectance values (image). It is important for studies involving multi temporal and more than one satellite image of one time (image mosaics), as it mostly removes variations between images due to sensor differences, earth-sun distance and solar zenith angle caused by different scene dates, overpass time and latitude differences etc (Bruce and Hilbert, 2004). In basic image processing, the conversion takes place in two steps; 1) DN to radiance conversion and 2) radiance to reflectance conversion (Haung et al., 2002; Chander and Markham, 2003 and Chander et al., 2009). The ERDAS Imagine 9.2 directly converts the Landsat (7) ETM+ images to reflectance images, where as other Landsat images (MSS and TM) can be converted to reflectance images using equations 1, 2 and 3 as proposed by (Chander et al., 2009). The needed information includes in-flight sensor calibration parameters and exoatmospheric irradiance values. The sensor calibration information (Gain, Bias, Solar elevation and Solar azimuth) are provided in metadata file with satellite images, while the exoatmospheric irradiance values (earth-sun distance in astronomical units and solar spectral irradiance) for Landsat 5 and 7 are available from Markham and Barker (1986) and NASA’s Landsat 7 Science Data Users Handbook (2003) respectively. Chander et al. (2009) provide full details of sensor calibration parameters and exoatmospheric irradiance values, earth-sun distance in astronomical units and algorithms of DN to radiance and radiance to reflectance conversion etc. for all three sensors of Landsat i.e. MSS, TM and ETM+. The direct methods of converting DN values to reflectance image of Erdas Imagine 9.2 did not produce good results. Thereafter, conversion of DN to reflectance was applied to images in two steps i.e. DN to radiance and radiance to reflectance.

As per NASA’s Landsat 7 Science Data Users Handbook (2003), DN to radiance conversion takes place using the following equations.
$L = \text{Gain} \times \text{DN} + \text{Bias} \ldots \ldots \text{eq 1}$

The above stated equation can also be expressed as:

$L_{\lambda} = \frac{\left( L_{\lambda}^{\text{MAX}} - L_{\lambda}^{\text{MIN}} \right)}{\left( \text{QCAL}_{\lambda}^{\text{MAX}} - \text{QCAL}_{\lambda}^{\text{MIN}} \right)} \times \left( \text{QCAL} - \text{QCAL}_{\lambda}^{\text{MIN}} \right) + L_{\lambda}^{\text{MIN}} \ldots \ldots \text{eq 2}$

Where: $L_{\lambda}$ = Spectral Radiance measured over spectral bandwidth of a channel in watts/(meter squared * ster * µm)

$\text{Gain} = \text{Rescaled gain in watts/ (meter squared * ster * µm)/DN. It is also known as Gain which is calculated using the equation } \frac{L_{\text{MAX}} - L_{\text{MIN}}}{255}$

$\text{Bias} = \text{Rescaled bias in watts/ (meter squared * ster * µm). It is also known as Bias, which is } L_{\text{MIN}}$.

$\text{QCAL} = \text{It is quantized calibrated pixel value in DN}$

$L_{\lambda}^{\text{MIN}} = \text{It is spectral radiance scaled to QCALMIN in watts/(meter squared * ster * µm)}$

(lowest radiance measured by detector in mWcm$^{-2}$ sr$^{-1}$)

$L_{\lambda}^{\text{MAX}} = \text{It is spectral radiance scaled to QCALMAX in watts/(meter squared * ster * µm)}$

(radiance measured at detector saturation in mWcm$^{-2}$ sr$^{-1}$).

$\text{QCALMIN} = \text{The minimum quantized calibrated pixel value (corresponding to } L_{\lambda}^{\text{MIN}} \text{) in DN.}$

All landsat images are in 8 bit unsigned form the values for which range from 1-255. Therefore, the QCALMIN is 1.

$\text{QCALMAX} = \text{The maximum quantized calibrated pixel value (corresponding to } L_{\lambda}^{\text{MAX}} \text{) in DN = 255}$.

The second step was to convert the radiance images to reflectance images that was done using the following equation as suggested by NASA’s Landsat 7 Science Data Users Handbook (2003).

$\rho_{\lambda} = \pi d^2 L_{\lambda} / E_{0\lambda} \cos \theta_s \ldots \ldots \text{eq 3}$
Where: \( \rho \) = Reflectance as a function of bandwidth  
\( d \) = Earth-sun distance in astronomical units.  
\( L \) = Radiance as a function of bandwidth  
\( E0 \) = Mean solar-exoatmospheric irradiance  
\( \theta \) = Solar zenith angle in degrees.

The above stated steps still did not produce desired results, since the final DN values were exaggerated and the images were in darker side. Hence, absolute atmospheric correction method called DOS was also required in addition to the conversion to reflectance image. Therefore, a new model developed by RS/GIS Lab, Utah State University using the Chavez (1996) COST method was applied. The model combines two steps of conversion of DN to reflectance image with DOS reflectance, while normalizing solar elevation angle using the following equation.

\[
\rho_{\text{BandN}} = \pi \left( (L_{\text{BandN}} \times \text{Gain}_{\text{BandN}} + \text{Bias}_{\text{BandN}}) - (H_{\text{BandN}} \times \text{Gain}_{\text{BandN}} + \text{Bias}_{\text{BandN}}) \right) \times \frac{D^2}{E_{\text{BandN}} \times (\cos((90-\theta) \times \pi / 180))^2 \times 400}) \text{........eq 4}
\]

Where: \( \rho_{\text{BandN}} \) = Reflectance for Band N  
\( L_{\text{BandN}} \) = Digital Number for Band N  
\( H_{\text{BandN}} \) = Digital Number representing Dark Object for Band N  
\( D \) = Normalized Earth-Sun Distance in astronomical units  
\( E_{\text{BandN}} \) = Solar Irradiance for Band N

The results of application of above stated equation on satellite images were satisfactory (Figure 6.2).

![Figure 6.2 Raw (a) and Corrected (b) Satellite Images of NDBR](image-url)
6.3.5 Topographic Correction and Normalization

Difference in illumination caused by changing angle of sun relative to slope angle and aspects of earth surface as a result of high altitude variations and rugged topography distort brightness of satellite images (Bruce and Hilbert, 2004 and Sotomayor, 2002). Therefore, the correction of distorted brightness values of satellite images is an important aspect of image pre-processing. This procedure is also known as topographic normalization. It significantly reduces the effects of different sun angles, earth’s slopes and aspects on brightness values of satellite images. It requires the satellite image and DEM of same spatial resolution and informations about sun elevations in study area (Bruce and Hilbert, 2004).

There are two types of topographic normalization models viz. Lambertian and Non-Lambertian. The Lambertian model assumes that surface reflects incident solar energy uniformly in all directions and the variation in reflectance is due to the amount of incident radiation. Whereas, Non-Lambertian model observes surface does not reflect incident solar energy uniformly in all directions. Instead, it takes into account variations in the terrain and lead to more accurate results. For the present study, the Landsat MSS, TM and ETM+ images have been topographically normalized to Lambertian model using ASTER GDEM2.

6.3.6 Remote Sensing of Vegetation and NDVI

Remote sensing images have been widely used for the study of variety of aspects of vegetation including mapping and assessment of vegetation and biodiversity, disturbance, stress, pigmentation, greenness, photosynthetically active vegetation, density of vegetation, tree line detection etc.

Figure 6.3 Spectral Responses of Dry Soil, Wet Soil and Vegetation (Source: Sotomayor, 2002)
Different types of surface objects including vegetation (species, density, richness, water stress, greenness etc.) reflect energy in different quantity in different electromagnetic spectrums (Figure 6.3). These different types of reflections can be used for variety of aspects of vegetation study (Table 6.2).

Table 6.2 Principle Application of Various Bands of TM and ETM+ for Vegetation Studies

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength (µm)</th>
<th>Principle Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>Band 2: 0.525 - 0.605</td>
<td>Designed to measure green reflectance peak of vegetation for vegetation discrimination and vigor assessment.</td>
</tr>
<tr>
<td>Red</td>
<td>Band 3: 0.630 - 0.690</td>
<td>Designed to sense in a chlorophyll absorption region aiding in plant species differentiation.</td>
</tr>
<tr>
<td>Near IR</td>
<td>Band 4: 0.760 - 0.900</td>
<td>Useful for determining vegetation types, vigour, and biomass content, for delineating water bodies, and for soil moisture discrimination.</td>
</tr>
<tr>
<td>Mid IR</td>
<td>Band 5: 1.550 - 1.750</td>
<td>Indicative of vegetation moisture content and soil moisture.</td>
</tr>
<tr>
<td>Thermal</td>
<td>Band 6: 10.40 - 12.5</td>
<td>Useful in vegetation stress analysis, soil moisture discrimination, and thermal mapping applications.</td>
</tr>
<tr>
<td>Mid IR</td>
<td>Band 7: 2.080 - 2.35</td>
<td>Sensitive to vegetation moisture content.</td>
</tr>
</tbody>
</table>

One of the important techniques to study the vegetation changes over time is NDVI (Solaimani et al., 2011 and Phong, 2004). NDVI has also been widely used to assess changes in photosynthetically active (green) vegetation in relation to climate change (Shilong et al., 2005 and 2011 and Zhou et al., 2001). The NDVI uses Red and Near Infrared bands, which is based on contrasting spectral properties of photosynthetically active (green) vegetation and its soil background. It reduces the impact of varying illumination conditions and shadow effects caused by solar variations and viewing angle of instrument (Lillesand et al., 2004). The NDVI yields the image with DN values ranging from -1 to +1. The values between 0.2 to 0.4 refer to vegetation and more than 0.4 to forests cover. The remaining values between 0.2 to -1 represent non vegetated areas such as bareland, snow and ice, etc. Following equations yields the NDVI.

For Landsat TM and ETM+ images, the NDVI calculation is denoted as follows:

\[ \text{NDVI} = \frac{\text{band}4 - \text{band}3}{\text{band}4 + \text{band}3} \] \hspace{1cm} \text{eq 5}

For Landsat MSS images, the NDVI calculation is denoted as follows:

\[ \text{NDVI} = \frac{\text{band}4 - \text{band}2}{\text{band}4 + \text{band}2} \] \hspace{1cm} \text{eq 6}
6.3.7 Re-sampling and Change Detection of NDVIs

All the corrected images were re-sampled to the resolution of Landsat MSS i.e. 60 m. Though, the spatial resolution of Landsat MSS is 72 m, but they were already re-sampled to 60 m, when downloaded from the website of USGS-glovis. Therefore, the ETM+ and TM were re-sampled to 60 m. Thereafter, NDVI was applied to all the satellite images used. The area of NDBR was subset from all the NDVI images. The non-vegetation areas were removed using the threshold of 0.2. All the other values above 0.2 were considered as vegetation areas. Areas above the value of 0.2 were further classified in four categories viz. 0.2-0.4, 0.4-0.6, 0.6-0.8 and 0.8-1.0. Further, the pixels of each category were counted for calculation of area. The change detection technique has been applied in order to assess the change of spectral signatures of different categories of NDVI (vegetation) in relation to climate change. The areas of change for different categories of vegetation could not be calculated as a large number pixels representing non-vegetation cover were also included in the calculation. The results have been visually compared.

6.4 Results and Discussion

6.4.1 Vegetation Change

The analysis of NDVIs values representing only vegetation cover (more than 0.2) shows that photosynthetically active vegetation has changed over the years. It does not, however, at all indicate the changes in total vegetation cover. Instead, it only represents the vegetation that was photosynthetically active to given climatic conditions. The total area of pixels representing the vegetation in October-1979 was 1632.9 km$^2$ that increased to 2041 km$^2$ in October-1999 and further decreased to 1519.1 km$^2$ in November-2010. It shows that photosynthetically active vegetation increased up to 1999 in relation to 1979 and later decreased up to 2010 in relation to 1999. Interestingly, the area of NDVI representing the values between 0.2-0.4 increased in all observation years. The area of values this range increased from 862.1 km$^2$ in October-1979 to 920.6 km$^2$ in October-1999 and 932.7 km$^2$ in November-2010. Contrary to this, the NDVI values representing higher values of vegetation showed different trends. They increased during 1979 to 1999 and thereafter showed negative trend during 1999-2010. Sharp decrease of NDVI values were observed in the categories of 0.6-0.8 and 0.8-1.0 (Table 6.3 and Figure 6.4).

The increase of active vegetation in all NDVI categories between the years of 1979 and 1999 can be directly attributed to climatic warming as indicated by various climate related studies across the world (IPCC, 2007a, Shilong et al., 2011 and Srinivasan and Joshi, 2007). Since acquisition date of both the satellite images i.e. 26 October 1979 and 15 October 1999 were
Figure 6.4 Temporal NDVIs
very close, the change of photosynthetically active vegetation can be regarded as the close approximation of climate change.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Categories</td>
<td>Pixel count</td>
<td>Area (km²)</td>
<td>Pixel count</td>
</tr>
<tr>
<td>OTV</td>
<td>1342204</td>
<td>4831.96</td>
<td>122863</td>
</tr>
<tr>
<td>0.2-0.4</td>
<td>239483</td>
<td>862.1</td>
<td>255723</td>
</tr>
<tr>
<td>0.4-0.6</td>
<td>119953</td>
<td>431.8</td>
<td>156289</td>
</tr>
<tr>
<td>0.6-0.8</td>
<td>87741</td>
<td>315.9</td>
<td>139711</td>
</tr>
<tr>
<td>0.8-1.0</td>
<td>6413</td>
<td>23.1</td>
<td>15208</td>
</tr>
<tr>
<td>Sub total</td>
<td>453590</td>
<td>1632.9</td>
<td>566931</td>
</tr>
<tr>
<td>Total</td>
<td>1795794</td>
<td>6464.9</td>
<td>1795794</td>
</tr>
</tbody>
</table>

On the other hand, the decrease of photosynthetically active vegetation especially in higher NDVI values, which represent the dense vegetation, between 1999 and 2010 can be primarily attributed to three reasons: 1) the date of satellite image acquisition i.e. 10 November 2010, 2) relatively heavy snow conditions at the time of image acquisition and 3) the decrease of global average temperature after 2003. In the month of November, chlorophyll content of vegetation decreases and most of the higher altitude grasslands turn to bareland and that leads to lower reflectance and greenness and eventually to lower NDVI values.

Also, there was a difference of about 22 days between the acquisition dates of satellite images of 1999 and 2010. The image of 2010 was acquired after 22 days of acquisition date of 1999. The vegetation in November is photosynthetically less active than that of October. Therefore, the vegetation at two different stages of growth was compared. It may also lead to relatively less active vegetation in month of November. The NDVI values shifts downward with the onset of winters. It may be associated with decreased areas of higher values of NDVI i.e. 0.6-0.8 and 0.8-1.0 and increased areas of lower values i.e. 0.2-0.4 in the year 2010. The image of November 2010 has relatively heavy snow conditions. It also led to overall lower NDVI values in 2010. The other important factor that may lead to lower areas under higher NDVI values may be the decrease of global average temperature especially after 2003. Decrease of temperature leads to lowering of photosynthesis process and eventually to lower active vegetation.
6.4.2 Changing Spectral Signatures of Vegetation and their Responses to Climate Change

The analysis reveals that there have been significant changes in spectral signatures of vegetation in study area. During the period of 1979 and 1999, vegetation activity increased in almost all the areas of NDBR. Surprisingly, decreasing vegetation activity was noticed in lower altitudes of river valleys of southern parts and in higher altitudes of northern part. The higher altitudes of southern parts show significant increase of vegetation activity.

In the Mana valley, the vegetation activity decreased in areas near the snouts of Satopanth and Bhagirath glaciers and in the vicinity of Tipra Kharak glacier. The study does not show any indication of vegetation advancement near the snouts of Satopanth and Bhagirath glaciers. The vegetation activity increased in upper altitudes of Tipra Kharak glacier, which represents the vegetation advancement in this area. Rana et al. (2010) proved the vegetation upward shift in this part of NDBR. The vegetation activity was also found to increase in upper areas of Barmal valley and upper Nakthani valley. In the upper valley of Saraswati, clear distinction is visible on east and west facing slopes. The slopes facing west show more active vegetation and also the increase of vegetation activity relative to east facing slopes. The south facing slopes show characteristics of east facing slopes, while north facing slopes show similar characteristics to west facing. In Nakthani and Barmal valley, such distinction was not observed.

In the Dhauli Ganga valley, the spatial pattern of change of growth was different from Mana valley. The east facing slopes shows increasing vegetation activity especially upto Malari village. On the other hand, the west facing slopes show decreasing vegetation activity. The Girthi Ganga valley, west Kamet glacier and Lapthal area show significant negative changes in the active vegetation. Opposite to the trend of Tipra valley, the vegetation activities have increased on the south facing slopes of Kosa glacial region, which is located on the right side of Tipra glacier separated by Ghori parbat. In the NDNP, the upper valleys show increase of active vegetation over the Nanda Devi glaciers. Contrary to this, the lower areas show negative trend.

The spatial patterns of changing vegetation in Milam Valley were similar to Mana valley. East facing slopes show decreasing vegetation activity and west facing increasing activity. The upper areas close to Milam glacier show negative changes of active vegetation. No general trend is visible in all the valleys of NDBR. Each valley shows a different trend. Also, there are significant differences within the valleys (Figure 6.5). It is perhaps the result of spatial changes of climatic conditions in NDBR, which could not be determined in paucity of surface observatories in different ecological zones and altitudes.
Figure 6.5 Changing Spectral Signatures of Vegetation: Responses to Climate Change
The post 1999 results reveal a clearer picture. In most part of the study area, there was significant negative change in active vegetation. In fact, there were only few areas where positive change could be determined. It might be necessarily related to month of the image acquisition. The other reason might be prevailing climatic conditions of year of 2010. Studies in different parts of the world are in general agreement that photosynthetically active vegetation or vegetation growth has changed in view of changing average temperature and precipitation conditions in northern hemisphere. A statistically significant positive trend of average growing season NDVI has been observed as a result of increasing temperature. However, the growing season NDVI decreased in a few areas, which was related to the remarkable decrease in summer precipitation (Shilong et al., 2011).

In view of satellite images and climatic records used in present study, only the changes of NDVI values between 1979 and 1999 can be correlated with climatic records of post 1980s, as these periods are in close proximity to each other. The changes of NDVI values between 1999 and 2010 could not be included in further analysis of their relationships with the climatic conditions, as the climatic records for this period were not available. Similarly, the changes of climate between 1955 and 1980 are not taken into account as the satellite data for same time period was unavailable. Also, the climatic data of post-monsoon season is correlated with changing NDVI values, as the images used in this study were of this season.

Study suggests that post-monsoon rainfall has decreased in both the parts of reserve. The overall decrease of rainfall during the period of 1981-2005 was more in western part (-1.18 mm/year) than western part (-0.43 mm/year). The temperature significantly increased in both the parts of reserve. The mean minimum temperature increased by 1.7°C in both the districts during the years of 1981-2002. The mean maximum temperature also increased by 1.4°C and 1.3°C in Chamoli and Pithoragarh districts during 1981-2002.

Relatively dry and warmer conditions lead to water stress in vegetation. Therefore, vegetation in very high altitudes of northern parts has become less active during the period of 1979-1999. However, it does not completely explain the factors behind the increase of active vegetation at higher altitudes in southern areas and their spatial differences. There are areas within the valleys where vegetation activity shown mixed results. However, during field visits, it was noticed that tree line was very close to snowline. Alpine vegetations have advanced and colonized supraglacial moraines i.e. glaciers. Such phenomenon could not be assessed on satellite images due to course spatial resolution of satellite images.
6.4.3 Altitudinal Sequence of Vegetation: Indication of Climate Change

Altitudinal sequence of vegetation (Plate 6.1) can be correlated with climatic conditions that are similar to the relationships suggested by Evans and Clague (1994) in case of slope failures. According to them, the earlier lower altitude climatic conditions have shifted to higher altitudes in recent times as a result of climate change so as the slope failure characters. Similarly, an altitudinal gradation was noticed in vegetation also. At lower altitudes dense forests of *Pine* and *Deodara* were found (Plate 6.1a). Relatively lower density of forests was noticed at higher altitudes (Plate 6.1b). At relatively higher altitudes, a clear altitudinal gradation of *Pine* and *Deodara* was found (Plate 6.1c). *Betula Utilis*, a treeline specie was found colonizing further upslope areas (Plate 6.1d) and some pioneer species were found colonizing the areas further upslopes near glaciers snouts. In many cases, the species have colonized the supraglacial moraines. It is inferred that present higher altitudinal vegetation with lower density was at lower altitudes in recent times. It has shifted as a result of climate change.

Plate 6.1 Altitudinal Sequence of Vegetation Change. Plate 6.1a Dense Forests of *Pine* and *Deodara* at Lower Altitude. Plate 6.1b Relatively Lower Dense Forests at Higher Altitude. Plate 6.1c Altitudinal Gradation of *Pine* and *Deodara* at Higher Altitude. Plate 6.1d *Betula Utilis*: A Treeline Specie.
6.5 Conclusion

Climate change has led to significant changes in vegetation activity across the world. These changes are clearly visible in high latitude and high altitude areas. Mountains regions with high altitude variations such as NDBR have witnessed even more drastic and surprising trends. IPCC and various other researches show the advancement of vegetation zones in view of changing climate. However, no such trend was significantly visible in NDBR. Instead, there was negative change in many areas. The high altitude areas of Lapthal reported significant decrease of vegetation activity. In the southern areas, the vegetation activity has increased significantly.

References


