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Assessment of Net Primary Productivity (NPP) of Forest Over Nainital District Using Remote Sensing

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ABSTRACT

We tested whether and up to what extent a remote sensing net primary productivity (NPP) estimation model based on the Landsat-8 data and GIS software can be used to estimate NPP. On the basis of forest inventory data for two multi date (10^{th} April and 3^{rd} Oct, 2015) images of Landsat-8 satellite and synchronous NDVI (Normalized Difference Vegetation Index) data, we used a satellite-based model (Piaoet al., 2005) for estimating NPP of sub-tropical forest of Nainital district. Using this model (Piaoet al., 2005), we analysed the changes in NPP over the multi date to identify the size and distribution pattern of the forest biomass. The total NPP of Nainital district was about 315.6 Mg ha^{-1}on 10^{th} April and 325.2 Mg ha^{-1} was on 3^{rd} Oct, 2015. Over the multi dates, the NPP increased by 9.6 Mg ha^{-1} over the study period from 10^{th} April to 3^{rd} Oct, 2015 and the change in productivity pattern was approximately 1.6 Mg ha^{-1} $month^{-1}$ which was probably due to favourable climatic conditions and optimum rainfall during the study period. Based on the results, we can conclude that, the major area (79%) of district was under forest.

Keywords- Net Primary Productivity, Remote Sensing, NDVI, BCD and carbon cycle.

I. INTRODUCTION

Net primary productivity (NPP) is a key component of the terrestrial carbon cycle, and it is defined as the accumulation of dry matters by green plants per unit time and space (Nayak*et al*., 2010). Although there are numerous measures of ecosystem function (e.g., energy flux, nutrient cycles, biodiversity), a key indicator is NPP (Knapp and Smith, 2001). Forest comprises a major part of terrestrial ecosystems occupying about 30% of the world's land area (Dixon *et al*., 1994), hence regional NPP estimation of these forest are very useful in modelling the regional and global carbon cycle as the carbon storage by terrestrial ecosystem as well as it play an important role in limiting the increasing rate of atmospheric CO_2 (Chen *et al*., 2000).

Forest acts as a source and sink of carbon and carbon is main raw material for increasing biomass and productivity of the forest. The NPP are also very useful in many of the studies associated with terrestrial ecology such as estimating crop yield (Patel *et al*., 2006), forest growth and production (Amiro*et al*., 2000), impact of human induced land degradation (Wessels*et al*., 2007) and impact of climate change on terrestrial biosphere (Nemani*et al*., 2003). NPP represents the amount of carbon that is retained by plants after assimilation through photosynthesis and autotrophic respiration (Cihlar*et al*., 2000) and represents the net carbon input from atmosphere to terrestrial vegetation (Mellilo*et al*., 1993). It is a measure to evaluate forest structure, function and quality. At the same time, NPP is also a basis for estimating the carbon budget of ecosystems and plays a key role in the understanding of carbon exchange between vegetation and atmosphere under both current climate condition and climate change caused by the human-induced increase in atmospheric CO_2 concentration (Wang *et al*., 1995). Therefore, a better understanding of NPP of forests will improve the estimation of global carbon cycle and enhance the ability of forest management under changing global environment. Study of NPP is a core task of International Geosphere – Biosphere Program (IGBP) and Kyoto Protocol (IGBP, 1998).

Traditionally, NPP has been measured using biometric measurements, i.e., sample surveys and field measurements (Tao *et al*., 2003). Although these traditional field-based measurements have been used successfully with accurate NPP output for small scale observations (Ogawa, 1977; Li *et al*., 2005), they are often time consuming and laborious (Lu, 2006). The methods are also hard to extend to the estimation of NPP on large scales because of the sparse measurements network. Also the need to fell sample tree sat the target research site may adversely affect the site, for example, loss of habitat, biodiversity and carbon sequestration potential (Wang *et al*., 2007).

Therefore, it is necessary to apply alternative methods of NPP estimation to replace or supplement traditional approaches in collecting ecological data. The development of remote sensing has by far enhanced the ability to study and understand ecosystems with improved accuracy (Lu, 2006). Remote sensing provides a valuable opportunity to improving the estimation of NPP at landscape and regional scales in a cost effective, efficient and accurate approach (Running *et al*., 1999; Running, 2000) at high temporal and spatial scales (Tucker *et al*., 2001). As a result, various NPP estimation models that use remote sensing data have been developed (Goetz *et al*., 2000). Recently, the Landsat-8 meteorological approach was developed (Running, 2001) to provide a consistent, continuous estimate of photosynthetic production (Running et al., 1999). Remote sensing offers a consistent and readily updated source of information for the quantification, monitoring and verification of aboveground NPP and carbon sinks from regional to global scales (Curran *et al*., 1994), so remote sensing data may provide a useful means for measuring carbon stocks in forests (Jiang *et al*., 1999). A promising advance technology in remote measurements, e.g. scanning lidar (a pulsed laser), new type of sensor that explicitly measures canopy height, the VCL mission (the Vegetation Canopy Lidar Mission-VCL), improve the ability to successfully measure forests carbon (Means *et al*., 1999; Lefsky*et al*., 1999).

On the basis of forest inventory data and synchronous NDVI (Normalized Difference Vegetation Index) data, we used a satellite-based model (Piao*et al*., 2005) for estimating NPP of sub-tropical forest of Nainital district. Using this model (Piao*et al*., 2005), we analysed the changes in NPP over the multi date to identify the size and distribution of the forests biomass also.

This study was done for sub-tropical forest of Nainital district. Nainital is a popular hill station in the Indian state of Uttarakhand. Nainital district situated at 29.23°N latitude and 79.27°E longitude with an altitude of 2,084 metres (6,837 ft) above sea level.Total geographical area of Nainital district is 4,251 km^2 (Census of India, 2011). The major portion of Nainital is covered with forests which are rich resources of Govt. revenue in the form timber wood, turpentine extraction from Pine trees, various types of herbs etc. For the management of this vast resource there is a setup of forest departments consisting of Conservator, DFOs, Rangers, and Foresters etc. For conserving forest based resources Van Panchayats have been organized in the district there are around 400 Van Panchayats in the district (Brief Industrial Profile of Nainital District).

In this study we tested whether and up to what extent the Landsat-8 data, model (Piao*et al*., 2005) and GIS software can be used in the estimation of NPP in Nainital district.

II. MATERIALS AND METHODS

2.1. Study site

This study was done for sub-tropical forest of Nainital district (Fig. 1.). Nainital is a popular hill station in the Indian state of Uttarakhand. Nainital district situated at 29.23°N latitude and 79.27°E longitude with an altitude of 2,084 metres (6,837 ft) above sea level, it is set in a valley containing a pear shaped lake. It has temperate summers with maximum temperature 27 °C and minimum temperature 7 °C. In winter, Nainital district receives snowfall between December and February with the temperatures varying between a maximum of 15 °C and a minimum of -3 °C (Wikipedia, 20/5/2015). The hilly region of Nainital district is covered with Sal, Pine, Oak, Buruns, Kaphal and other trees. There are small tracts of cultivated lands and fruit orchards in between the forests in this region. Kosi is the main river of the district .River Kosi arising out of Koshimool near Kausani flows on the western side of the district. There are number of smaller rivulets like Gaula ,Bhakra , Dabka , Baur etc. Most of these have been dammed for irrigation purposes. The forest cover is2,98,336 ha which is73.4% of total geographical area of 4,06,433 ha in 2006-07 (Brief Industrial Profile of Nainital District). Total geographical area of Nainital district is 4,251 km^2 and had a population of 9,54,605 (Census of India, 2011).

2.2. Remote sensing data

In this study, multi dates images of Landsat-8 were used and analysed for estimation of NPP of sub-tropical forest of Nainital district. Satellite images has been acquired from website of USGS (website http://glovis.usgs.gov/). LANDSAT – ETM + images of path 145 and row 40 were used. The scene of satellite images belonging to Nainital on 10th April and 3rd Oct, 2015 were downloaded from the above website.

2.3. Image Processing

2.3.1. Pre processing

The images were processed by using ENVI-4.8 image processing software and for digitization of district boundary of Nainital district we have used Arc-GIS software. After downloading images, the files from the images were extracted and subsettings of the images were done by using ENVI vector file (evf format) of Nainital district. After subsettings of the images, atmospheric corrections of the images were carried out using Quick Atmospheric Correction (QUAC) technique in order to remove the atmospheric error (Path radiance).

2.3.2. Post processing

After that we made five region of interest (water body, forest, river/stream, crop land and built up land) which was for discrimination of forest cover from other spatial features. We made the polygons and different colors were chooses for different ROI. Supervised classification (Fig. 2. & 3.) technique (maximum likelihood algorithm) was used for discrimination of different objects in both the LANDSAT-ETM+ images using ROI. Classification gives the information about the area of different classes used in classification.

2.3.3. NDVI generation

After supervised classification, NDVIs were generated for the images by using the formula and illustrate in the Fig. 4. & 5.

NDVI= (float(b5)-float(b4))/(float(b5)+float(b4))

$$\text{or}\,\mathbf{NDVI} = \frac{\text{NIR}-\text{R}}{\text{NIR}+\text{R}}$$

The NDVI is the vegetation index which is related to NIR (b5) and Red (b4) band of the Landsat-8 image. The colour of NDVI images are brighter where there are more vegetation and darker where there are water bodies. NDVI values varies from -1 to +1, +1 for brightest and -1 for darkest pixel of image. By the classification of images we got the total area under forest in Nainital district, and by NDVI we got the value of NDVImax which used in the model (Piao*et al*., 2005) for calculating biomass carbon density (BCD), to estimate the NPP. On the other hand, among the various tasseled cap indices, greenness index and wetness index showed positive relationship with the biomass while the brightness index was found to be negatively correlated. Dong *et al*., (2003) also found positive relationship of NDVI with biomass.

2.3.4. Calculation of BCD

Biomass carbon density (BCD) was expressed as the function of the corresponding NDVImax and forest locations of the area (longitude and latitude) for both the images by using model (Piao*et al*., 2005).

$$\mathbf{BCD}=111.521\,ln(\text{NDVI})-0.452\text{lat}-20.034\text{lon}+0.08568\text{lon}^2+1278.29$$

Where, BCD is forest biomass Carbon density (Mg C ha^{-1}), NDVI is NDVImax, *ln* is anti-log, lat and lon are latitudes and longitudes, respectively of study area.

2.3.5. Calculation of NPP

The calculation of NPP (Mg ha^{-1}) were done using factor of 2 based on the fact of 0.5 (Lieth and Whittaker, 1975; Myneni*et al*., 2001; IPCC, 2006), which is used to convert biomass (NPP) into carbon content by formula.

NPP = BCD*2

Where, BCD is forest biomass carbon density (Mg C ha^{-1}) and 2 if factor for conversion of carbon into NPP (Mg ha^{-1}).

III. RESULTS AND DISCUSSION

3.1. Total forest area

On the basis of forest inventory data and synchronous NDVI (Normalized Difference Vegetation Index) data, we used a satellite-based model (Piao*et al*., 2005) for estimation of NPP over multi date images of sub-tropical forest of Nainital district. The forest area used in this study were 3,34,228 and 3,34,318 ha, which were about 79.79% and 79.82% of total geographical area (4,18,855 ha) for image of 10th April and 3rd Oct, 2015 respectively. Similar forest area of 2,98,336 ha which was73.4% of total geographical area (4,06,433 ha) was observed in 2006-07 (Brief Industrial Profile of Nainital District). Figure.2. & 3.illustrates the distribution of the forest area, indicating a highly spatial heterogeneity which reflects differences in forest types and ages, climatic conditions, soil properties, and disturbance intensity of human activities.

3.2. NDVI

The NDVI of both images calculated separately using band math option of image processing software (ENVI-4.8). The NDVImax were observed as 0.603552 and 0.630319 for 10th April and 3rd Oct, 2015 respectively, which were acceptable.

3.3. Biomass Carbon Density (Mg C ha^{-1})

The biomass carbon density (BCD) was expressed as the function of the corresponding NDVImax and forest locations of the area (longitude and latitude) for both the images by using model given by (Piao*et al*., 2005).

$$\mathbf{BCD}=111.521\,ln(\mathrm{NDVI})-0.452\mathrm{lat}-20.034\mathrm{lon}+0.08568\mathrm{lon}^2+1278.29$$

Where, BCD is forest biomass Carbon density (Mg C ha^{-1}), NDVI is NDVImax, *ln* is anti-log, lat and lon are latitudes and longitudes of study area.

The biomass Carbon densities for 10th April and 3rd Oct, 2015 were calculated as 157.8 Mg C ha^{-1} and 162.6 Mg C ha^{-1}, respectively. Similar result was also expressed by Dixon *et al*, (1994), that the biomass carbon densities 114 Mg C ha^{-1} for china's forest.

Table.1.Total geographical area (TGA), Forest area (10^{3}ha), Forest percentage (%), Biomass Carbon Density (BCD), NPP (Mg ha^{-1}) and Total biomass over the district (million tonne)

Date of image acquisition	TGA (10^{3}ha)	Forest area (10^{3}ha)	Forest percentage (%)	BCD (Mg C ha^{-1})	NPP (Mg ha^{-1})	Total biomass (million tonne)
10th April, 2015	418.855	334.228	79.79	157.8	315.6	105.48
3rd Oct, 2015	418.855	334.318	79.82	162.6	325.2	108.72

3.4. Net Primary Productivity (Mg ha^{-1})

The calculation of NPP (Mg ha^{-1}) were done using factor of 2 based on the fact of 0.5 (Lieth and Whittaker, 1975; Myneni*et al*., 2001; IPCC, 2006), which is used to convert biomass (NPP) into carbon formula.content by

NPP = BCD*2

Where, BCD is forest biomass carbon density (Mg C ha^{-1}) and 2 if factor for conversion of carbon into NPP (Mg ha^{-1}).

The NPP for 10th April and 3rd Oct, 2015 were calculated and depicted as 315.6 Mg ha^{-1} and 325.2 Mg ha^{-1}, respectively and area obtained in forest cover by classification of images were 3,34,228 ha and 3,34,318 ha, respectively which were further used for calculation of total biomass (Table. 1.) over the district.

The total biomass (million tonne) over the district calculated based on NPP (Mg ha^{-1}) and area covered under forest. Total biomass for 10th April and 3rd Oct, 2015 were 105.48 and 108.72 million tonne, respectively over the district during the study period.

In our approach, we selected NDVImax as one of the predictors of biomass carbon density and NPP instead of growing season average NDVI, because this could explain more variation of biomass carbon density. The length of growing season is sometimes hard to be defined (it is long in the south and short in the north), but it can be eliminated by using NDVImax. Additionally, our approach uses longitude as one of predictors of biomass carbon density, because forest structures such as forest type and stand age differed greatly from east to west owing to the difference in climate and human activity density (Wang *et al*., 2001).

The major limitation of the study is that we did not use ground data to validate the model used. Thus, further research is needed to test the model based on ground truth analysis with results from biometric methods in Nainital land-scape. Nonetheless, our results are consistent with those obtained from NPP research in tropical forest.

IV. CONCLUSION

The objective of this study was to test whether and up to what extent a remote sensing NPP estimation model based on the Landsat-8 data and GIS software can be used to estimate NPP and we find that, remote sensing based model can successfully use to model NPP in sub-tropical forest of Nainital forest. Based on the results, we can conclude that, the major portion (79%) of district was under forest. The total NPP of Nainital district was about 315.6 Mg ha^{-1} on 10th April and 325.2 Mg ha^{-1} was on 3rd Oct, 2015. Over the multi dates, the NPP increased by 9.6 Mg ha^{-1} over the study period from 10th April to 3rd Oct, 2015 and the change in productivity pattern was approximately 1.6 Mg ha^{-1} month^{-1}. Precise estimation of forest biomass at regional or global scales is a significant research challenge. In this assignment, an empirical statistical model and NDVI data for estimating NNP of forest were used. NDVI, a good fitness between independent inventory biomass density and corresponding estimates from model indicates that coarse resolution remotely sensed data in combination with relevant geographic data (longitude and latitude) can be used to map distribution of NPP and forest biomass with a relative good accuracy over large areas.

V. ACKNOWLEDGEMENTS

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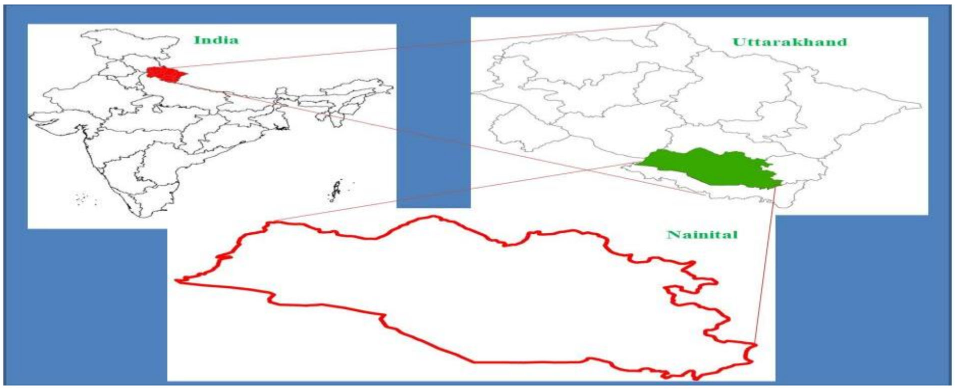

Figure. 1. Layout of study area (Nainital district)

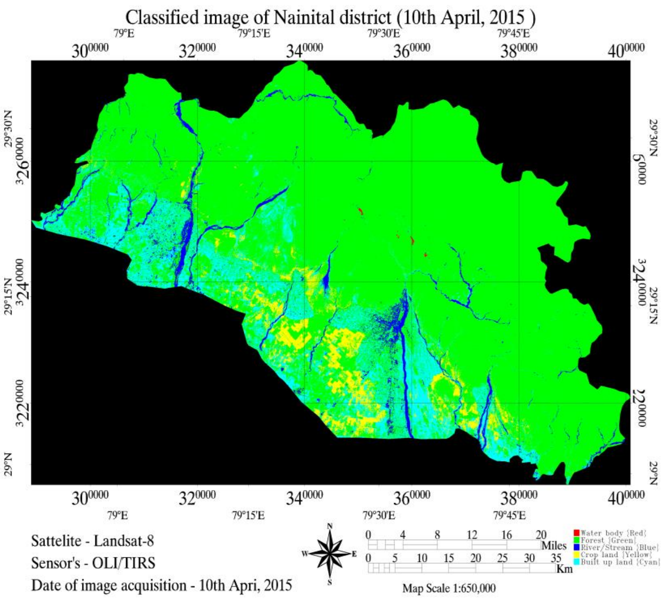

Figure. 2. Classified image of Nainital district (10th April, 2015)

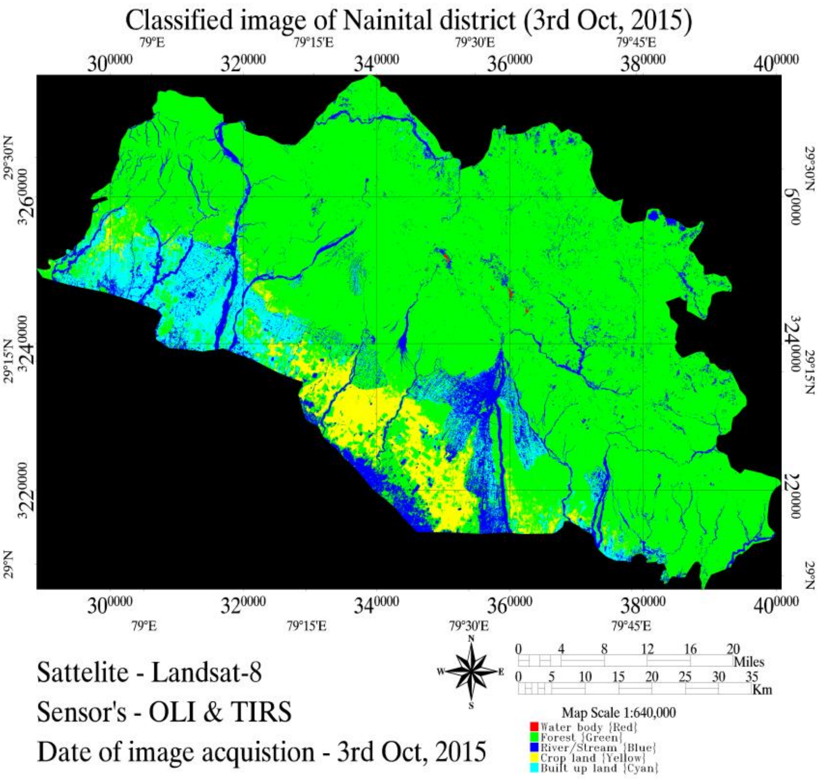

Figure. 3. Classified image of Nainital district (3rd Oct, 2015)

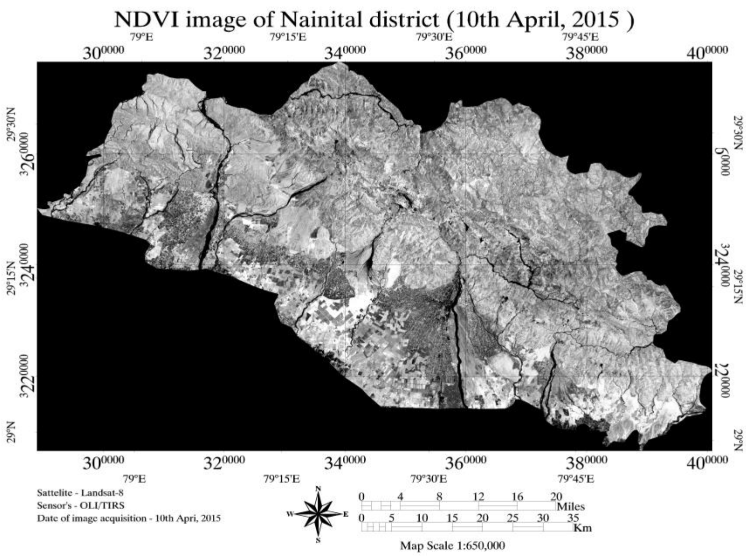

Figure. 4. NDVI image of Nainital district (10th April, 2015)

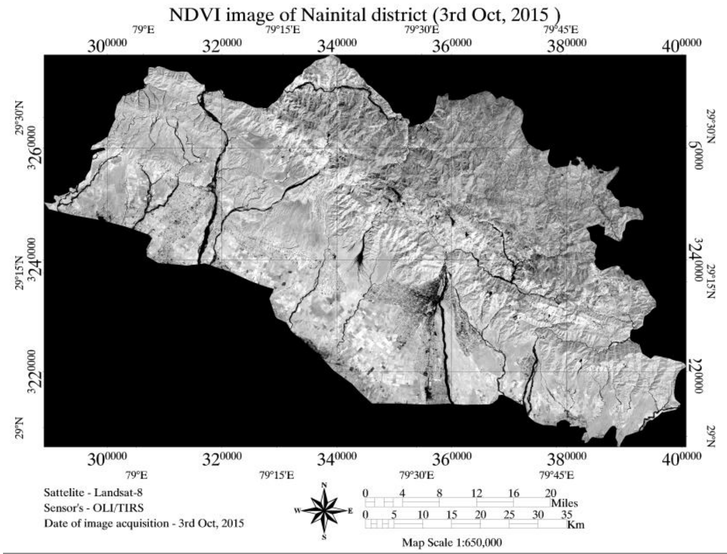

Figure. 5. NDVI image of Nainital district (3rd Oct, 2015)

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