SPATIAL DISTRIBUTION MAPPING OF NITROGEN CONTENT OF ALPINE PASTURE OF WESTERN HIMALAYA USING HYPERSPECTRAL REMOTE SENSING

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ABSTRACT: Nitrogen is one of the most important elements for vegetation health, a change in the concentration of which can affect the entire ecosystem. With the changing climate, it is expected that all the natural systems will be directly or indirectly affected. Alpine pastures are predicted to be the most sensitive ecosystem affected by climate change. This study attempts to develop a regression model to relate hyperspectral data with the vegetation nitrogen mass of alpine pastures of Himalaya, which is rich in biodiversity and medicinal plant treasure. Hyperion, moderate spatial resolution hyperspectral satellite data was used in the present study. Various pre-processing techniques were used to attain the reflectance satellite data. Alpine pasture region was extracted from the study area using Support Vector Machine (SVM). It was found to have accuracy of 86% and Kappa accuracy of 0.83. In the extracted alpine pasture region, field survey was carried out and in situ data (spectral signature, vegetation samples) was collected. Vegetation samples collected from the field was analyzed for nitrogen estimation using CHNS (Carbon, Hydrogen, Nitrogen and Sulphur) analyzer. Nitrogen was related with the vegetation spectra. Continuum removal technique was used for enhancement of nitrogen absorbance wavelengths. It was found that red and red edge region of electromagnetic spectra were found to be highly correlated with nitrogen content. Using this information, various vegetation indices were used to correlate the nitrogen content estimated from field. Modified Red Edge Normalized Difference Vegetation Index (MRENDVI) was found to have highest correlation of nitrogen mass with field observation and satellite data. The wavelengths used for the index were at 752nm, 701nm and 447nm of Hyperion image. The regression model developed using MRENDVI and nitrogen mass was $y = 3.18x – 0.62$. Using this relation, nitrogen distribution map was prepared with nitrogen mass ranging from 2 kg/ha to 12 kg/ha. The alpine pasture areas which were adjacent to the barren land had lower nitrogen concentration, whereas the areas near temperate forests had higher nitrogen concentration. The study infers that red edge region is sensitive to nitrogen in the plant and can be used to determine the health of vegetation. It can also be suggested that high spatial resolution satellite data with red edge band can be an alternative to the hyperspectral satellite data with vegetation growth monitoring.

INTRODUCTION

Nitrogen (N) is an essential element for plant growth and development, and an excellent indicator of vegetation health status. The structure of all living organisms contains protein which has nitrogen as an integral component. Nitrogen plays vital role in ecosystem structure and functioning. Besides total nitrogen of an ecosystem, foliar nitrogen is equally important as it is directly linked to photosynthetic rate, photosynthesis capacity and net primary productivity (NPP) (Birk and Vitousek 1986; Field and Mooney 1986).

Alpine pastures are very important from the management and conservation point of view. It is rich in biodiversity and medicinal values but is one of the most sensitive ecosystems affected by climate change (Sala *et al.* 2000; Bisht and Bhatt 2011). The medicinal plants of alpine pastures are important for economy of the region. Due to climate change, these important species are susceptible to extinction. In Uttarakhand, state of Indian Himalayan Region (INR), alpine meadows (locally called *bugyals*) are found below the bare rocks from 3000 m ASL to 5000 m ASL. The alpine meadows are followed by subalpine conifer forests and temperate broadleaf forests.

It is predicted that nitrogen change will be one of the most important impact of climate change affecting ecosystems, especially alpine and temperate grasslands (Sala *et al.* 2000). The traditional way of estimation of nitrogen from the ecosystem had been a tedious task. Samples were collected from each point and brought back to the laboratory for analysis. The remote areas of mountains are difficult to access and this leads to less collection of samples from the area. This has resulted in loss of past data from the region. With advancement in technology, remote sensing has proven to be an important tool for analysis of biophysical and biochemical constituents from ecosystems present in remote areas. Hyperspectral remote sensing is one of the advanced technologies frequently used for estimation of nitrogen from canopy of plant. In the spectral reflectance of vegetation, nitrogen was found to absorb incident radiation in many wavelengths from red to Short Wave Infrared (SWIR) region of electromagnetic spectrum. Hyperspectral data provides this useful information using large number of bands in continuous and narrow wavelengths.
This study aims to develop a regression model to relate the Hyperspectral data information with foliar nitrogen in the alpine pasture region of Chamoli district of Uttarakhand. This will be helpful for estimation of Nitrogen in non-destructive way from alpine pastures of Uttarakhand. The nitrogen map of alpine pasture can be used by the forest managers to understand the health of alpine pasture vegetation and take further step for its conservation and protection.

STUDY AREA

Uttarakhand is a Himalayan state in northern India and lies between 28°53'24" to 31°27'50" N latitude and 77°34'27" to 81°02'22" E longitude. Uttarakhand is a mountainous state covering 93% of its area with altitude ranging from 195 m ASL to 7816 m ASL. The alpine pasture area chosen for the study lies in Chamoli district of Uttarakhand and the area is present between 79°19'23.916" E, 30°28'47.789" N and 79°28'0.555" E, 30°51'41.745" N with altitude ranging between 3162 m ASL and 4909 m ASL. Location of the study area is shown in Figure 1. Alpine pasture region falls between timberline and snowline. This zone is marked by scattered patches of *Betula*, *Rhododendron anthopogon*, *Juniperus* sp. along with grasses and sedges. In local language, alpine pastures are called Bugyals and are famous tourist spots for camping and trekking.

Data

EO-1 Hyperion data (21st June 2013) of path 145 and row 39 was used to estimate the standing nitrogen content. L1R and L1T products of Hyperion sensor were used as the hyperspectral data. L1R is the radiometric corrected data which was used for nitrogen estimation. While L1T product is used for the georeferencing of L1R data. Hyperion data has 242 bands (wavelength ranging from 356 nm to 2577 nm) with spectral bandwidth of 10 nm. Other than satellite, some of the ancillary data were also used in this work. Vegetation type map (Roy *et al.* 2012) was one of the most useful data. It was used during reconnaissance survey.

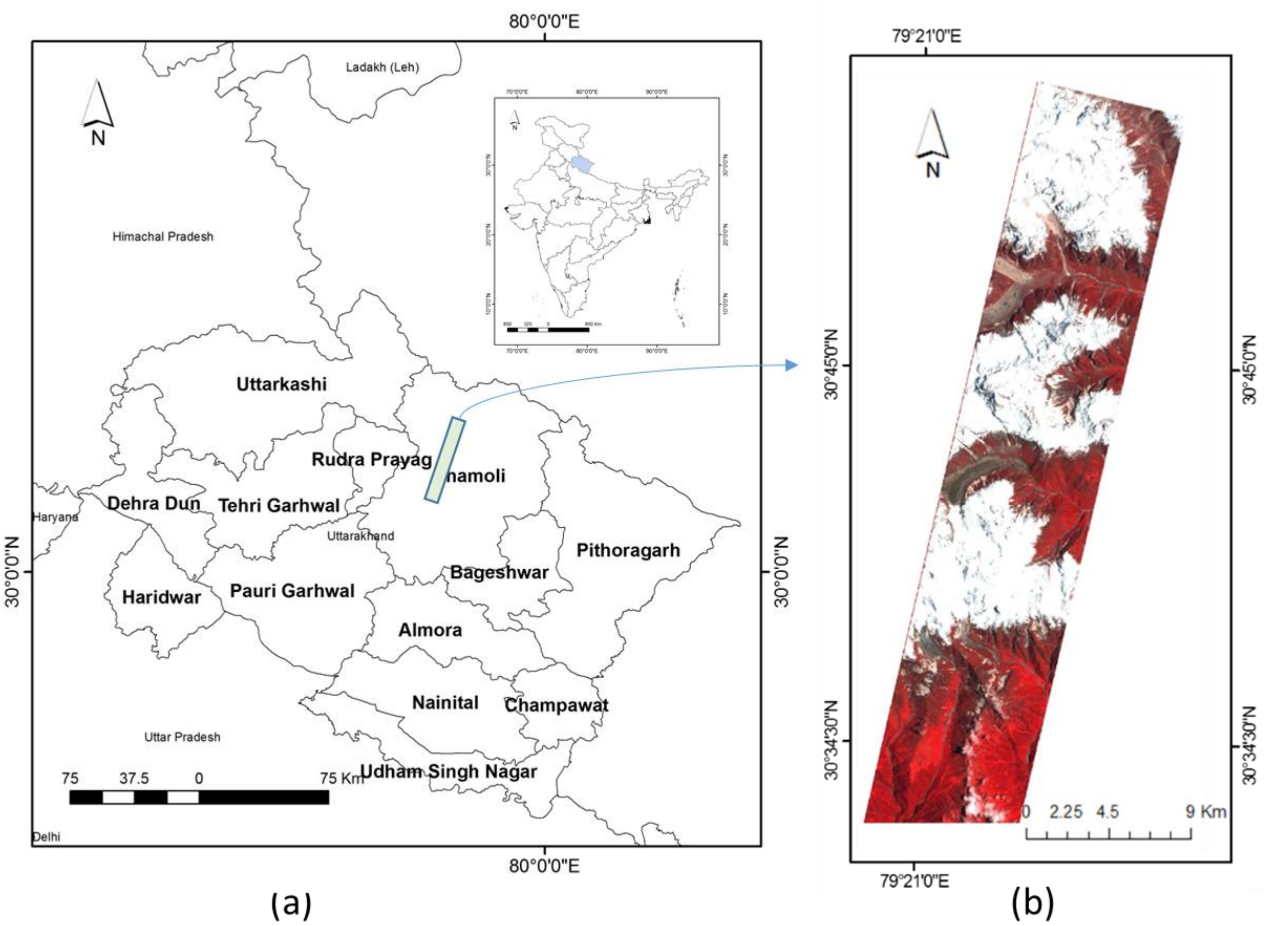

Figure 1. (a) Location of study area (b) False Colour Composite of Hyperion data (study area)

METHODOLOGY

The methodology for the study involves pre-processing of Hyperion data, satellite image classification, field data collection, nitrogen estimation from field data and remote sensing data, and development of regression model relating foliar nitrogen to the hyperspectral data.

Pre-processing and classification of Hyperion data

The Hyperion image consists of 242 spectral bands, from which the bands with very high noise were removed manually by spectral subset tool in ENVI software. De-stripping was done using an extension called ‘workshop’ which fixed the outliers. The efficiency of the process of destripping was checked using the Signal to Noise Ratio (SNR), using band math in ENVI. FLAASH (Fast Line-of- sight Atmospheric Analysis of Spectral Hypercube) tool was used for atmospheric correction of the images. For the present study, L1R product of Hyperion data was used after geometric correction using terrain corrected L1T product of same sensor, Hyperion. The processed image was used for supervised classification using parallelepiped, maximum likelihood, SAM (Spectral Angle Mapper) and SVM (Support Vector Machine) algorithm were used in ENVI software.

Field data collection

The field investigation was carried out on the anniversary date of the pass of Hyperion sensor data to minimise the phenological variation in the plant. The objective was to collect the leaf samples and spectra of the same using spectroradiometer and verification of alpine pasture classified using satellite data. Stratified random sampling method was used for field data collection. Since, the alpine pasture mostly contained herbs, plots of 1m×1m size were laid. Fresh weight of samples was taken in the field.

Nitrogen estimation

Nitrogen was estimated from field collected samples using Elementer CHNS (Carbon, Nitrogen, Nitrogen and Sulphur) analyser. For Nitrogen estimation from Hyperion data, Nitrogen absorption bands were identified using the band depth analysis from the collected spectra. The raw reflectance data from the Hyperion sensor data corresponding to the ground coordinates collected during the field were measured in each of the specified bands as canopy spectral reflectance. First and second order derivatives were also used for the enhancement of spectral property. Continuum removal was used for the absorption depth analysis of the hyperspectral data. Most sensitive bands with nitrogen concentration were used in vegetation indices (VI) to map nitrogen distribution. Most suitable VI was identified and the results were used to correlate with the foliar nitrogen estimated from the field data. Likewise, the spectral reflectance of leaf obtained from the ground was statistically analysed with the foliar nitrogen. Then, the results from the Hyperspectral image and the results from the spectroradiometer were validated. Using the regression model, leaf nitrogen mass (LNM) map was prepared for alpine pasture. The nitrogen mass map generated was further subjected to the accuracy assessment and validation. Half of the samples were used to generate the nitrogen mass map and rest were used to measure the accuracy of the map. Coefficient of determination was calculated to estimate the accuracy of the nitrogen mass map.

RESULTS

Thorough reconnaissance survey was carried out in the study area to identify the plant species. Mostly herbaceous species viz. *Cotoneaster microphyllus, Danthonia* sp., *Primula* sp., *Poa* sp. and *Potentilla* sp. were present with scattered shrubs of *Juniperus communis and Rhododendron anthopogon*.

Pre-processing of satellite data

Out of the total 242 bands, 124 bands were used for further analysis and the remaining bands were removed during bad band removal. The dark vertical stripes in image were minimized by de-stripping. After Atmospheric correction using FLAASH, Geometric correction was done using terrain corrected product (L1T) of Hyperion. The RMSE error in the geometric correction was 0.25 which can be considered for the further processing.

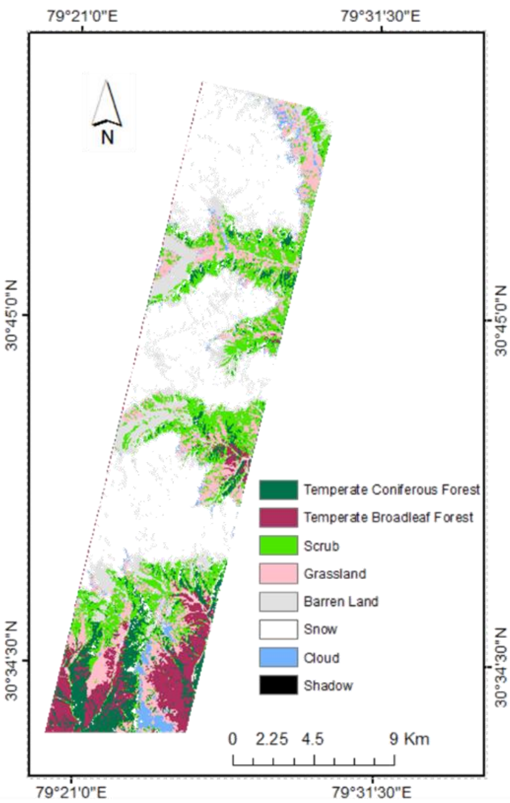

Figure 2. Classified map of study area

Classification of Hyperion image

As the species information was already available from the extensive reconnaissance survey, supervised classification technique was carried out on the platform provided by ENVI. The Hyperion data was classified into temperate broadleaf forest, temperate coniferous forest, grassland, barren land and snow. Since the Hyperion is moderate spatial resolution satellite data, it was difficult to discriminate different species present in the alpine pasture. Hence grassland was considered as a single class for alpine pasture. Out of all the classifiers mentioned in the methodology, SVM had highest accuracy of 86%. The accuracy of classification using SAM, Parallelepiped and maximum likelihood were 84%, 80% and 82%. The classified map of the study area using SVM (shown in Figure 2) was used for further analysis.

Field data collection and nitrogen mass analysis

19 plots were laid down from which 324 sampled were collected from the study area. The nitrogen analysis was done using CHNS analyser. The results showed that minimum foliar nitrogen was 1.19% and maximum was 3.42%. The average nitrogen % was found to be 2.16 ± 0.76 %. The average nitrogen mass in the vegetation type was found to be 2.98±1.34 Kg/ha. The minimum nitrogen mass was found to be 1.67 Kg/ha whereas the maximum was 6.79 Kg/ha. The increment was due to small saplings of junipers present in the plot. Table 1 shows the plot wise nitrogen mass in alpine pasture vegetation type.

Table 1. Plot wise details of nitrogen content, dry mass and estimated nitrogen mass

Plot No.	**N %**	**Dry Mass (Kg/ha)**	**Nitrogen Mass (Kg/ha)**
1	1.27	206.44	2.62
2	1.26	386.14	4.87
3	1.26	196.35	2.47
4	1.46	162.33	2.37
5	1.83	147.39	2.70
6	1.95	167.79	3.27
7	1.19	346.32	4.12
8	1.35	154.68	2.09
9	1.72	97.00	1.67
10	2.20	152.61	3.36
11	2.13	158.12	3.37
12	2.38	122.49	2.92
13	3.42	59.23	2.03
14	2.91	62.26	1.81
15	1.76	118.52	2.09
16	2.84	60.68	1.72
17	3.08	55.03	1.69
18	3.29	143.15	4.71
19	2.77	245.02	6.79

Derivative analysis:

First and second order derivative were computed for field as well image based spectra. The correlation analysis was performed between leaf nitrogen mass and derivative spectra. The Correlogram diagram for the study area is shown in Figure 3. Derivative spectra from field data showed more significant results than the satellite based derivative spectra. It was also observed that first order derivative was sufficient for identification of suitable wavelengths for nitrogen estimation. However, the correlation data from first as well as second derivative spectra has also been presented. The wavelengths with high correlation and significance for nitrogen estimation were found to be at 523 nm, 579 nm, 660 nm, 681 nm, 694 nm, 752 nm, 1699 nm, 2082 nm and 2365 nm. Overall, it was observed that the correlation of derivative spectra with nitrogen mass in the SWIR region was not that much significant as compared to the relation in the visible region of EMR. The wavelengths in the red edge region (691 nm -701 nm) showed consistent and high correlation for both the field and satellite image derived first and second derivative. Other than red edge, the wavelengths nearby 450 nm, 560 nm, 660 nm and 750 nm showed good correlation values.

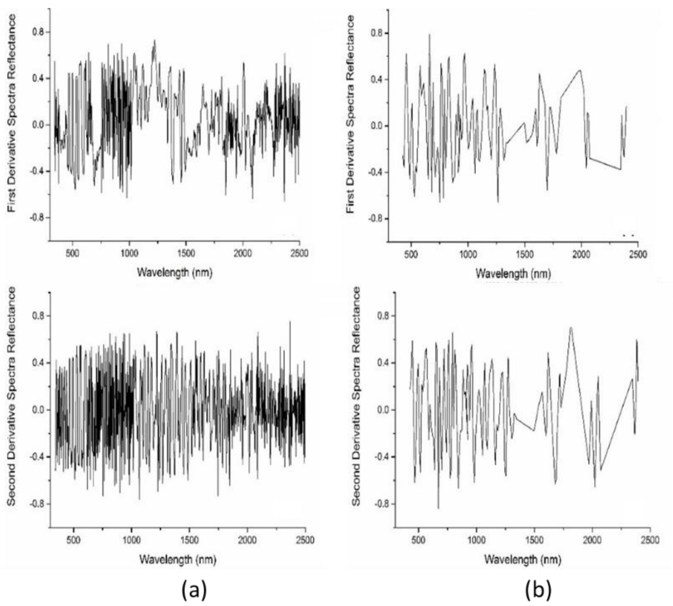

Figure 3. First and Second order derivative from (a) field data (b) satellite data

Analysis from the derivative spectra were used to study the variation in the nitrogen content in red region which is most sensitive for nitrogen absorption. In red region, the presence of nitrogen in due chlorophyll pigment which shows the absorption in spectral reflectance curve. To enhance the absorption, continuum removal technique was used. The nitrogen concentration found from study area was related with the continuum removed spectra. Figure 4 shows the absorption depth in the visible region due to nitrogen concentration. The absorption is concentrated near the wavelength at 690 nm. From the continuum-removed spectra, it was observed that in the red region absorption is more prominent than the SWIR region.

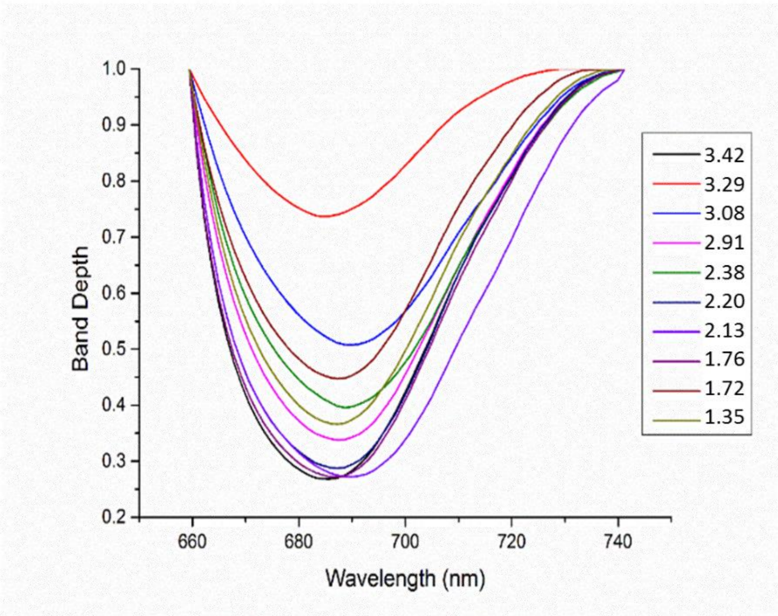

Figure 4. Variation in nitrogen content with respect to absorbance in red edge region

Identification of suitable vegetation index and mapping of foliar nitrogen mass

Most of the bands in the SWIR region were affected (as the data was of monsoon season) and removed during the bad band removal because of the moisture. The analysis was done with the remaining band in the SWIR region and no significant bands were present to establish the relationship with nitrogen content. The results of the analysis with visible and NIR region showed Red edge region to be most successful in the study area. The vegetation indices with red edge band was used in the correlation analysis. The list of the red edge indices used for the study area and its correlation values are given in Table 2.

Table 2. Relation between different vegetation indices and nitrogen mass in the study

vegetation Index	**correlation (r)**	
	Field	**Image**
Red Edge Normalised Difference Vegetation Index (RENDVI)	0.89	0.81
Normalised Difference Red Edge Index (NDRE)	0.85	0.79
Modified Red Edge Simple Ratio (MRESR)	0.82	0.81
Vogelmann Red Edge Index 2 (VREI2)	0.81	0.76
Modified Chlorophyll Absorption Ratio Index (MCARI)	0.52	0.61
Modified Chlorophyll Absorption Ratio Index 2 (MCARI2)	0.61	0.54
Modified Red Edge Normalised Difference Vegetation Index (MRENDVI)	0.93	0.83
Transformed Chlorophyll Absorption Ratio Index (TCARI)	0.19	0.36
Vogelmann Red Edge Index (VREI)	0.87	0.71

Modified Red Edge Normalized Difference Vegetation Index (MRENDVI) was found to have highest correlation with leaf nitrogen mass with field data (0.93) as well as image data (0.83). The wavelengths used for the index were 752nm, 701nm and 447nm of the Hyperion image. However, all the indices showed significant correlation except the chlorophyll indices. The regression model developed using the MRENDVI and LNM has been shown in Figure 5.

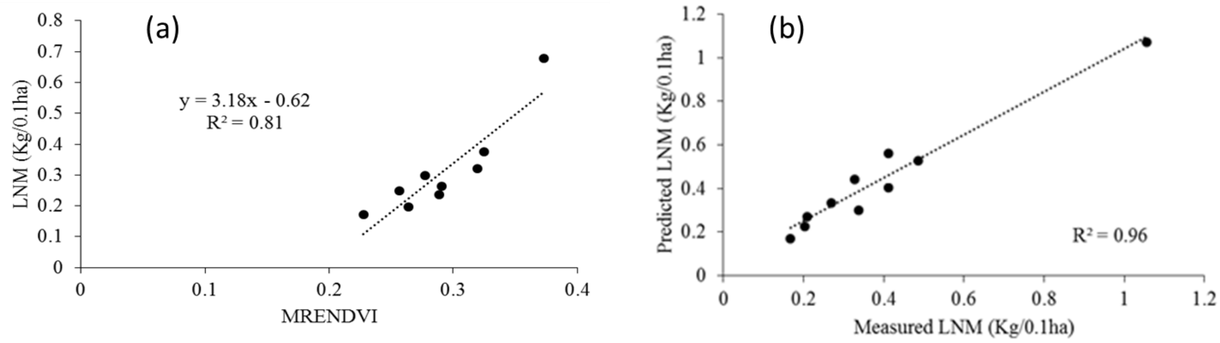

Figure 5. (a) Regression analysis between MRENDVI and Leaf nitrogen mass (b) Accuracy assessment of predicted nitrogen mass with measured nitrogen mass

Coefficient of determinant was found to be 0.81 showing significant relation between nitrogen mass and the index at 95% confidence level. The model developed was $y = 3.18x - 0.62$. This was applied to MRENDVI image of alpine pasture vegetation type. The output leaf nitrogen mass map is shown in Figure 6. Nitrogen mass in the alpine pasture region was found to vary between 0.2 Kg/0.1 ha to 1.2 Kg/0.1ha. At higher altitude, where the grassland was associated with the barren land, areas had lower nitrogen values, while the area associated with the temperate forest had higher nitrogen mass. The accuracy of the map was 96%, shown in Figure 5 (b).

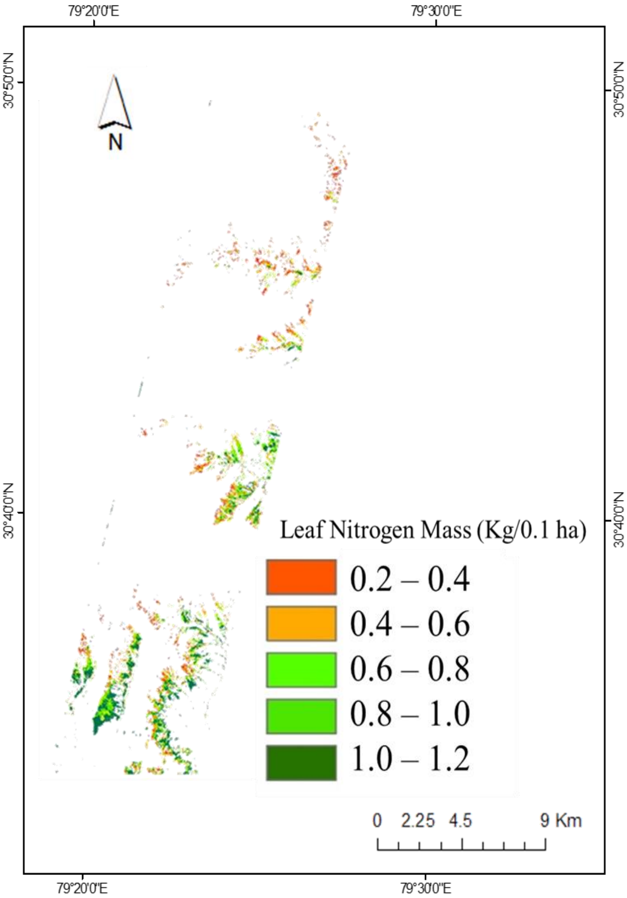

Figure 6. Nitrogen mass map of grassland in the alpine region of study area

DISCUSSION

The primary aim was to identify the suitable wavelengths for the nitrogen absorption. It was found that the wavelengths at 434 nm, 659 nm, 1015 nm, 1680 nm and 2365 nm were highly correlated with nitrogen content. Similar wavelengths of 430 nm, 660 nm, 1020 nm, 1510 nm and 1690 nm, 2060 nm and 2350 nm were also reported to be sensitive to Nitrogen in the previous studies (Curran, 1989; Lucas and Curran, 1999). It was found that the reflectance of Hyperion data after pre-processing and atmospheric correction is comparable to the handheld spectroradiometer, which was also concluded by Yuan and Niu (2008).

In the study, many classifiers were compared and SVM was found to have highest accuracy for Hyperion data classification. SVM had the flexibility of selection of threshold for separating the classes by introducing kernel function. SVM has also advantage that it does not redundant, once the boundary is established. Bazi and Melgani (2006) and George *et al.* (2014) also found SVM useful for classifying Hyperspectral data. Nitrogen content in the alpine pasture region in this study is comparable to the estimates of 0.53-3.56% given for alpine meadows of Garhwal Himalaya by Sundriyal and Joshi (1992). The difference in the grasslands of different mountain ranges can be due to the difference in the species composition.
The wavelengths around the visible region were found to be consistently providing good results in both field as well as image based spectra. The results of correlogram from image derived derivative spectra was non-significant because derivative spectra are sensitive to sensor noise. The decrease in signal to noise ratio limits the use of high derivative order. The spectral analysis done with the image was not as consistent as of from the field data. The reason being the presence of mixed species composition in pixels due to moderate spatial resolution of Hyperion data. The suitable wavelengths for nitrogen absorption found in the study were at 690 nm from both field as well as image spectra which were comparable to the nitrogen absorption wavelengths of 693 nm and 1770 nm given by Ferwerda *et al.* (2005). In the study, results from red region showed consistent relation with nitrogen from both ground as well as image. However, SWIR region was not considered due to the presence of moisture in the fresh samples. To overcome such problem, two or more wavelength combinations were used in the vegetation index. The results showed significant correlation of leaf nitrogen mass with MRENDVI (Modified Red Edge Normalised Difference Vegetation Index), with field as well as image spectral data. The wavelength combinations were from different zones of EMR, one was from the blue region (447 nm), another from Near Infrared region (752nm) and last one from red region (701nm). Blue and red region in the index are important for the absorption feature while NIR region show the maximum reflectance.

Nitrogen mass in the alpine pasture was predicted to be 2 kg/ha to 12 kg/ha. The region with low nitrogen content had rocky mountain and affected by the frequent grazing. While high nitrogen content regions were having variety of species and junipers. The region was also rich in biodiversity. The low nitrogen shows stress in the ecosystem. It is evident from the Study on Nitrogen content in the grasslands of KwaZulu-Natal, South Africa by Cho *et al.* (2013). The average nitrogen content was found to be lower due to high fragmentation in that region.

CONCLUSION

The suitable wavelengths for nitrogen absorption found in the study were at 447 nm, 470 nm, 670 nm, 690 nm, 701 nm, 752 nm, 1015 nm, 1514 nm and 1680 nm. It has been observed that the wavelengths from visible region showed higher correlation than the SWIR region. From the literature and observations from the current study, it can be concluded that bands in the SWIR region can be useful for nitrogen estimation, provided the sample should be dry. MRENDVI (Modified Red Edge Normalized Difference Vegetation Index) was found to be the best suited vegetation index to estimate and predict the nitrogen content. The index used three wavelengths at 447 nm (blue region), 701 nm (red edge region) and 752 nm (NIR region). This study gives prediction model for Nitrogen estimation using hyperspectral data. The nitrogen map produced in the study can be used to prioritize the areas of alpine pastures in Himalaya for conservation and protection. The map also shows the current health condition of the alpine pastures in Himalaya. Further study on the factors affecting the Nitrogen content and the health of this important ecosystem is recommended.

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