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Development of Narrow Band Index for Accurate Mapping of Chlorophyll in Senescent Stage of Teak (*Tectona grandis* L. f.) Using Hyperion (EO1) Data

DHAVAL VYAS
Dolat Usha Institute of Applied Sciences, Department of Microbiology, Valsad, Gujarat, 396001, India
E-mail: vyasdhaval84@gmail.com

ABSTRACT
Hyperspectral remote sensing sensors have shown a great promise towards the accurate estimation of chlorophyll content over a large spatial scale. However, most of the vegetation cover in tropics and subtropics attains maximum chlorophyll content in the monsoon season. The cloud coverage in this period of the year generates a major problem particularly with optical remote sensing data. Therefore, there is an extreme need to develop vegetation index using space borne reflectance spectra acquired from very low chlorophyll content samples (of senescent vegetation). In the present study an attempt has been made to develop accurate narrow band index for assessment of chlorophyll in senescent stage of teak (*Tectona grandis* L. f.) using Hyperion (EO1) data. Pearson's correlation coefficient (PCC) was calculated to identify the correlation between measured chlorophyll and Hyperion reflectance spectra (spectral subset 436-1346 nm). Wavelength with highest positive correlation and highest negative correlation were identified and selected for development of indices. SR 599/1134 gave the best results for prediction of chlorophyll in senescent teak vegetation cover with R^2 of 0.68 for linear regression model and cross validation R^2 0.67 and RMSE 0.15 g m^{-2}.

Key words: Teak, Hyperspectral remote sensing, Chlorophyll

INTRODUCTION

Chlorophyll is considered to be one the most important organic molecule of the Earth. Chlorophyll concentrations affect photosynthesis, which can be considered as the major driving force for life on the Earth (Nelson and Yocum 2006). Foliar chlorophyll concentrations, affect a number of major ecological events involved in exchange of matter and energy such as photosynthesis and carbon sequestration. Accurate estimates of foliar chlorophyll content can provide important information on ecosystem functioning, for example as an indicator of vegetation stress (Zarco-Tejada et al. 2012) and ecosystem productivity (Mooney 1986, Peterson et al. 1988, Blackburn 1998). Assessment of chlorophyll content is a practical and objective method to develop quick opinion on forest stress condition (Sampson et al. 2003). Hence, availability of precise chlorophyll maps has become a need of an hour especially for terrestrial ecosystems. Consequently, the accurate estimation of chlorophyll concentration at landscape scale is fundamental for the appraisal of an overall wellbeing of terrestrial ecosystem. Chlorophyll map of tropical forest ecosystems is of great importance as tropical forests shows huge variation in foliar chlorophyll content due to high floral diversity. On the other hand, only small portion of landscape is amenable to field based sampling whereas many parameters of tropical forest is distributed non-linearly across the environmental gradients (Chambers et al. 2007). Traditional methods (destructive sampling methods) for the assessment of chlorophyll content over a large spatial scale are time consuming and expensive. Therefore, assessment of chlorophyll at minute temporal scale becomes nearly impossible using traditional destructive methods. In contrast, measurement of spectral reflectance is nondestructive and rapid (Gamon and Qiu 1999). Remote estimation of leaf biochemical properties from various platforms has been the subject of many studies aimed at increasing our understanding of terrestrial ecosystem functioning (Wang and Li 2012). In the last decade or so Hyperspectral remote sensing sensors (Imaging spectrometers) has shown a great promise towards the accurate estimation of chlorophyll content over a large spatial scale. Zhang et al. (2008) said that Hyperspectral remote sensing has a great potential for accurate retrieval of forest biochemical parameters. Many researchers have estimated chlorophyll with the help of pixel level (airborne or spaceborne) hyperspectral reflectance spectra (Jago et al. 1999, Asner and Martin 2008, Darvishzadeh et al. 2008, le Marie et al. 2008, Schlerf et al. 2010, Stagakis et al. 2010, Vyas et al. 2013).

There are many techniques available to quantify foliage chlorophyll using reflectance spectra acquired by imaging spectrometers. Yet, technique of the development of vegetation indices is computationally fast and requires little expertise (Haboudane et al. 2008). Therefore, many vegetation indices were developed and tested for quantification of chlorophyll using imaging spectrometers (Sims and Gamon 2002, Darvishzadeh et al. 2008, le Marie et al. 2008, Stagakis et al. 2010, Wu et al. 2010). However, most of the vegetation indices were developed using reflectance spectra acquired from the vegetation having very high chlorophyll content per unit area or developed from the mixture of low chlorophyll content and high chlorophyll content samples (Darvishzadeh et al. 2008). In addition, availability of hyperspectral data at the high chlorophyll content stage of the vegetation is a major problem particularly in space borne Hyperspectral remote sensing studies in tropical region. Furthermore, most of the vegetation cover in tropics and subtropics attains maximum chlorophyll content in the monsoon season or just after the monsoon season. The cloud coverage over the vegetation in this period of the year also generates a major problem particularly with optical remote sensing data (for instance hyperspectral remote sensing data). Therefore, there is an earnest need to develop vegetation index using space borne reflectance spectra acquired from very low chlorophyll content samples (of senescent vegetation). Accurate estimates of chlorophyll of important species in senescent stage can help in evaluating the healthy status of tropical forest. Teak (*Tectona grandis* L. f.) is very important species of tropics known for their commercial and conservation values. Today it is widely planted in the tropical forests of South East Asia, and as exotic species in Africa, South and Central America (Ball et al. 1999). In tropical countries like India, Teak occurs across the region (Kaul et al. 2010). Keeping these aspects of Teak in mind the present study has been carried out with the objectives (a) development of vegetation index for estimation of very low chlorophyll content accurately from senescent vegetation covers of Teak, with the help of space borne hyperspectral data (Hyperion EO1), and (b) preparation of a valid foliar chlorophyll map of Teak vegetation cover of study area for a given time period using developed vegetation index.

MATERIAL AND METHODS

Study area

The study was conducted in tropical dry deciduous forests of Shoolpaneshwar Wildlife Sanctuary (SWS) located at 21°29’ –21°522’N lat. and 73°29’ –73°54’ E long., Narmada district, Gujarat, India **(**Fig. 1**)**. The SWS is one of the important protected areas of the state of Gujarat, supporting sizeable biota. The sanctuary remains covered with lush green vegetation in monsoon and shows dry vegetative condition in summers. Teak (*Tectona grandis* L. f.) is being planted under social forestry program by Forest department of Gujarat in SWS since last 10-15 years. Teak is well known for their commercial and conservation values. A large area is occupied by pure patches of Teak (~20%) in the forest of SWS (Vyas et al. 2011). Teak is a deciduous tree and its leaf fall initiates in the month of December. Leaf fall reaches up to 50 % in the month of January. As study was conducted in tropical dry deciduous forest region, forest surface at the time of data collection is devoid of any kind of green vegetation cover.

Field data collection

Total 20 quadrats of 30 × 30 m size were marked in the pure patches of Teak in the study area. Quadrat size coincides with spatial resolution of the Hyperion sensor (30 m). Each quadrat marked in pure patches of Teak fall in a patch size of 3×3 pixel window. Ground control points of each quadrat were recorded with the help of global positioning system receiver for each quadrat (Magellan® explorist 600, accuracy ± 5 m). A field survey was carried out in a month of January (winter season). Satellite data acquisition falls in this time window. The month of field data collection and image acquisition is identical to each other.

Measurement of leaf area

Number of trees and Girth at Breast Height (GBH) of each individual tree was measured in each marked

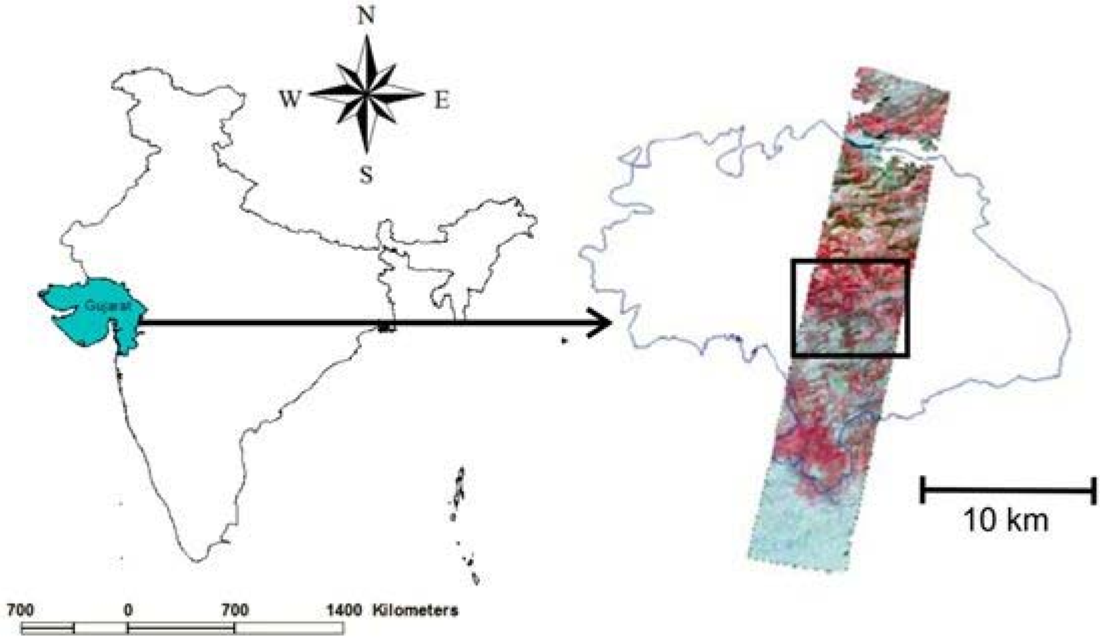

Figure 1. Study area

quadrat of Teak. Total 15 representative trees (with the range of GBH) from different quadrat were identified. Number of leaves present on the tree canopy was calculated by visual observation for each representative tree. Total 15 leaves from different side of the canopies of all the representative trees were sampled. Leaf area of each sampled leaf was measured. An average leaf area was multiplied with the total number of leaves of the each individual tree to get total leaf area per individual Teak tree. A regression (n = 15) equation was developed between GBH and leaf area. Care was taken to include the entire range of GBH and Leaf area in the developed regression model. With the help of developed regression equation leaf area of each individual tree in the quadrat was calculated. A total leaf area per quadrat was obtained for each quadrat by addition of leaf area of each individual tree of the quadrat.

Measurement of stand level total chlorophyll

Around 3-5 representative trees based on different girth size were selected in each quadrat for foliage sampling. The foliage samples were collected randomly from peripheral parts of the canopy of teak in the month of January. Precautions were taken so as to enable the inclusion of all kinds of leaves (varying size, shape, colour) seen across the canopy of a tree. Sampling period coincided with that of satellite data acquisition (20 day window). Samples were immediately brought to the laboratory for the biochemical analysis. Leaf discs (1 cm^2) were cut from each leaf and chlorophyll was extracted in dimethyl sulphoxide (DMSO). Chlorophyll content per unit leaf area was determined by following the procedure of Arnon (1949). The measured values were extrapolated to estimate chlorophyll content of the quadrat (mean chlorophyll per unit area × total leaf area of the quadrat / total area occupied by quadrat). From these values, stand level chlorophyll content ($g\ m^{-2}$) was determined.

Hyperion data acquisition and processing

Archived hyperion data was obtained. At the time of data acquisition cloud cover was less than 25% (Fig. 2). Spatial resolution of the sensor is 30 m and spectral resolution is 10 nm with a range of 427-2345 nm. Atmospheric correction was carried out using FLAASH software. Atmospheric correction was done on 196 bands after removing 46 non-calibrated and over lapping bands. Zero value bands were deleted and final image contained 165 bands (Christian and Krishnayya 2009). Image was geo-registered with WGS-84 Geodetic datum by ERDAS Imagine V.8.7 (RMSE 0.1 pixel). A subset was extracted from this image covering an area of 67.5 km^2**.** Subset area extracted coincides exactly with

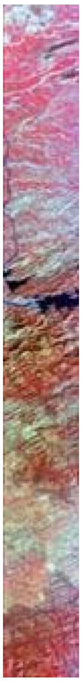

Figure 2. Full display of EO1H148045201102 2110Kj_PF1_01 image acquired (Shoolpaneshwar wildlife sanctuary)

the one covered in field survey. Subset extraction and image processing was performed by using ENVI V.4.6 software. After the preprocessing, GCPs of all the 20 quadrates were transferred to Hyperion image subset. Thereafter, reflectance spectra for all the marked quadrats were obtained for further analysis.

There are number of atmospheric agents which contaminate the content of various bands information. Earth's atmosphere contains CO_2, O_2, O_3, H_2O, CH_4, CO, NH_4, N_2O, and other nitrogen gasses, which interact with approximately 50% of the electromagnetic radiation spectrum over the region of 300-2500 nm (Gao and Goetz 1990, Gao et al. 1993). In the present study, Atmospheric correction of EO-1 Hyperion images was done using ENVI + FLAASH 4.5 software. With an input of calibrated hyperspectral radiance data, ENVI + FLAASH 4.5 produce an output of apparent surface reflectance. The hyperspectral data must be spectrally and radiometrically calibrated to use ENVI + FLAASH4.5.

Identification of wavelength for the development of index

A spectral subset (426 -1346 nm) was obtained from the entire Hyperion Reflectance spectra of all the 20 quadrats. To identify and understand the contribution of each wavelength towards the stand level chlorophyll content a Pearson's correlation coefficient (PCC) was calculated for each wavelength. Earlier, Thenkabail et al. (2000) and Xue and Yang (2009) used linear correlation analysis for development of indices. Axelsson et al. (2013) have identified most informative wavelength bands from airborne hyperspectral reflectance spectra based on the linear correlation coefficients. PCC for each wavelength were obtained using linear correlation tool of SPSS V20 statistical analysis software (n = 20). Wavelength with highest positive correlation and wavelength with highest negative correlation were identified and selected for development of Simple Ratio (SR) as well as Normalized Difference (ND) ratio Index.

Development of regression model and cross validation

Linear Regression Models (LMR) were prepared (between calculated SR and ND indices values and stand level chlorophyll content). Correspondingly, all the prepared models were cross validated using Leave One Out (LOO) cross validation method. LOO cross validation method was used by Darvishzadeh et al. (2008) for validation of developed models. Root Mean Square Error of cross validation ($RMSE_{CV}$) was also calculated for each cross validation procedure. Developed indices in present study were also compared with previously developed SR and ND indices for measurement of chlorophyll using space borne sensors.

Development of chlorophyll map

Regression model developed between vegetation index and chlorophyll content of teak was transferred into the band math tool of ENVI 4.5 for the production of the chlorophyll map. Output images reflect pixel-level chlorophyll values of vegetation teak covers. Teak pixels in the study area were identified using classification image derived from present study. Built in complex non-linear classification algorithm The Support Vector Machine

Table 1. Measured stand level total chlorophyll for Teak

Parameter	No. of observation	Standard deviation	Mean	Minimum	Maximum
Total chlorophyll (g m^{-2})	20	± 0.28	0.50	0.20	0.94

(SVM) from ENVI V.4.5 was used to classify image.

RESULTS AND DISCUSSION

Stand level chlorophyll content and hyperion reflectance spectra

Stand level total chlorophyll measured in the foliar samples ranged from 0.20-0.94 g m^{-2} (SD ± 0.28) in Teak quadrats (Table 1). Maximum value of measured stand level chlorophyll in this study is far lesser than ones published by others for assessment of chlorophyll content using Hyperspectral data. Earlier, Darvishzadeh et al. (2008) and Asner and Martin (2008) developed models using measured chlorophyll range of 0.10 to 2.70 g m^{-2} and 0.11 to1.93 g m^{-2}, respectively. Maximum and minimum (n = 20) reflectance spectra obtained from Hyperion sensor for marked Teak quadrats are shown in Figure 3. The Hyperion reflectance spectra of January month showed considerable variability among Teak quadrats. High disparity in reflectance has been observed especially in visible and FNIR region. Variation in visible region can be attributed to difference in chlorophyll content and other pigments. While, variation in FNIR region can be accredited to variability in Leaf Area Index (Vyas et al. 2013). The visible region of the Hyperion reflectance spectra showed an absorption pattern in the blue and red

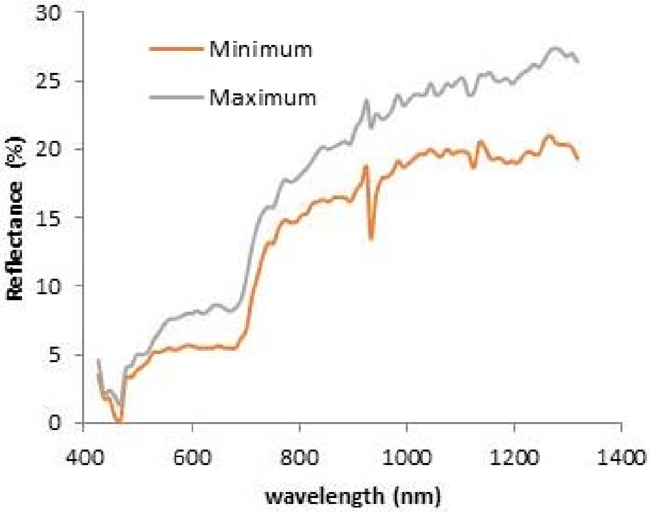

Figure 3. Maximum and minimum reflectance spectra of all the quadrats with Teak vegetation

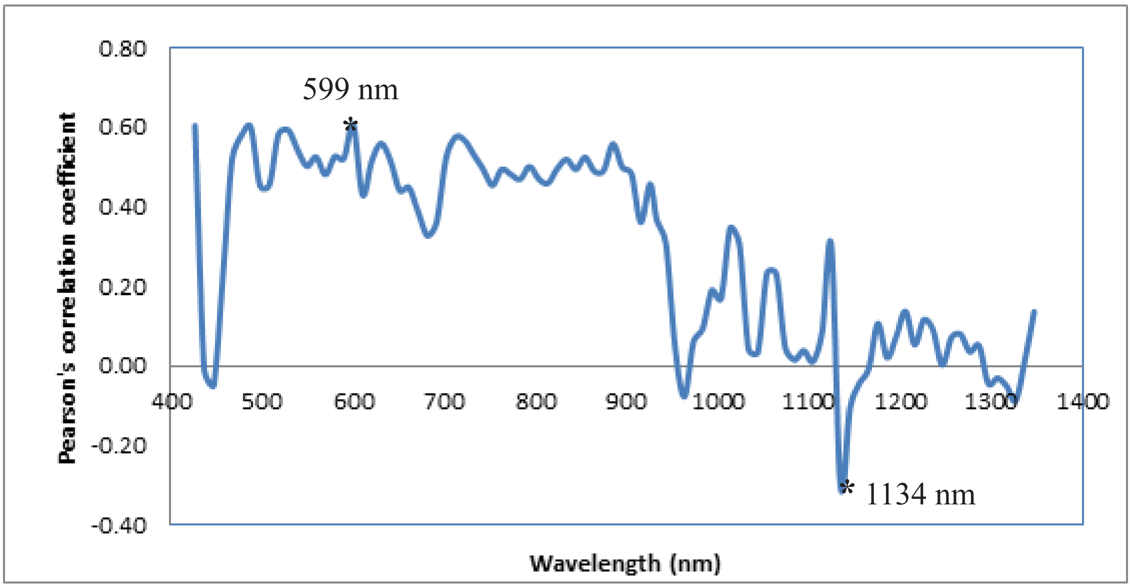

Figure 4. Pearson's correlation coefficient showing affiliation between stand level chlorophyll and reflectance values obtained from Hyperion reflectance spectra (426-1346 nm)

regions of electromagnetic spectrum. It's apparent that effect of chlorophyll content is present in Hyperion reflectance spectra obtained from Teak quadrats of senescent stage (in the month of January senescence of Teak reaches up to 50%). Earlier, Delegido et al. (2010) affirmed that chlorophyll molecules show clearly differentiated absorption bands: one in the blue region between 400 and 500 nm, and another in the red region between 600 and 700 nm.

Identification of wavelength and development of indices

Figure 4 shows the PCC generated between Hyperion reflectance spectra and measured stand level chlorophyll of Teak in the month of January. Numerous wavelengths especially in visible region of electromagnetic spectrum showed significant correlation with stand level chlorophyll (r > 0.50). Visible and NIR region showed positive correlation with stand level chlorophyll content while many wavelengths in FNIR region showed negative correlation with stand level chlorophyll content. Wavelength of 599 nm showed highest PCC (r = +0.60) whereas 1134 nm showed highest negative correlation (r = -0.30). These two wavelengths 599 nm and 1134 nm were selected for developing indices (SR and ND). Simple ratio (599/1134) gave best results for prediction of stand level chlorophyll with R^2 of 0.68 for developed linear regression model (Fig. 5). Similarly, ND 599, 1134 also gave fine results with R^2 of 0.67 for developed linear regression model (Fig. 6). Earlier, Carter and Knapp (2001) found R^2 peaks for chlorophyll between 548–599 nm in senescent foliage. Results of present study also support the importance of wavelength 599 nm for estimation of chlorophyll in senescent vegetation. Sensitivity of wavelength 1134 nm can be explained by results of Darvishzadeh et al. (2008) where number of wavelengths in FNIR region such as 1132, 1141 and 1150 nm found to be sensitive towards the canopy level total chlorophyll content. Furthermore, Gamon et al. (1997) and Delalieux et al. (2009) concluded that electromagnetic region around 550 nm have been found to be responsive to changes in photosynthetic radiation use efficiency and vegetation stress condition. Reflectance at 559 nm is found to be correlated with low chlorophyll content and stress condition.

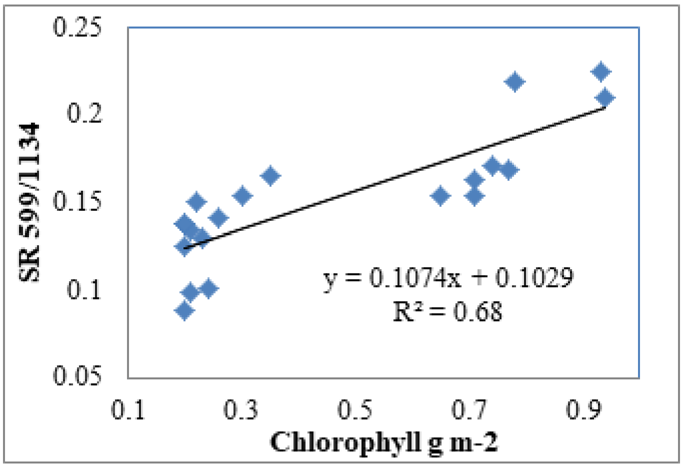

Figure 5. SLR model showing significant relationship between SR 599/1134 and stand level chlorophyll

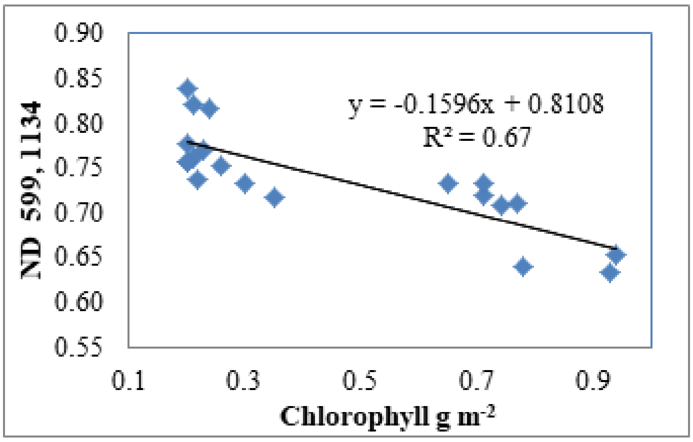

Figure 6. SLR model showing significant relationship between ND 599, 1134 and stand level chlorophyll

Cross validation and comparison with other indices

LOO cross validation procedure for SR 599/1134 resulted in R^2 of 0.67 with RMSE of 0.15 g m^{-2} (Fig. 7). Cross validation procedure for ND 599, 1134 resulted in R^2 of 0.66 with RMSE of 0.17 g m^{-2} (Fig. 8). Comparison of best performing index (based on % $RMSE_{CV}$ per mean value of chlorophyll) of present study with other developed indices of chlorophyll is shown in Table 2. Best performing index in present study SR 599/1134 showed $RMSE_{CV}$ of 30.00 %. This value is comparable to $RMSE_{CV}$ values acquired for chlorophyll indices developed by other researchers (le Maire et al. 2004, Darvishzadeh et al. 2008, Wu et al. 2010) particularly with low

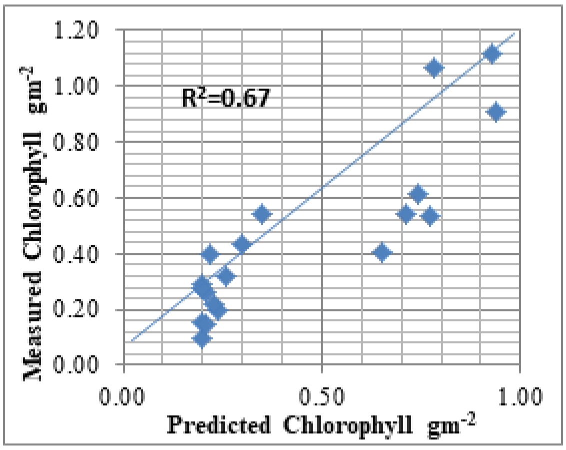

Figure 7. LOO cross validation results of SLR model prepared for SR 599/1134

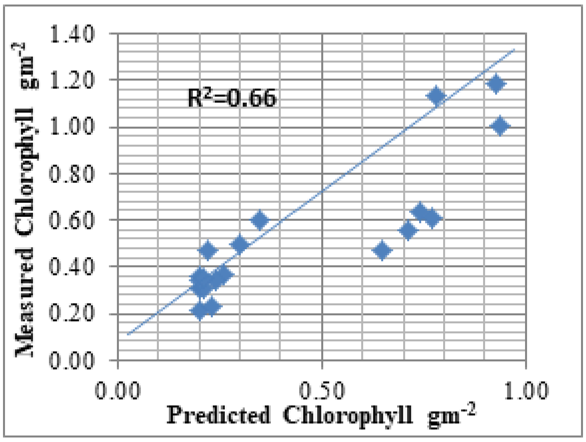

Figure 8. LOO cross validation results of SLR model prepared for ND 599, 1134

chlorophyll content range and less canopy cover of senescent stage of Teak. Results represented using % RMSE$_{CV}$ per mean value clearly shows that SR 599/1134 was competent to estimate very low chlorophyll content of vegetation in senescent stage with considerable accuracy.

Chlorophyll map

Figure 9 shows the process of chlorophyll map development along with classified Hyperion image of January month using SVM and all 165 bands. Over all classification accuracy obtained for October and January Hyperion (EO1) image is 73%**.** Chlorophyll maps produced for teak vegetation covers depicted the distribution pattern of chlorophyll in the study area**.**

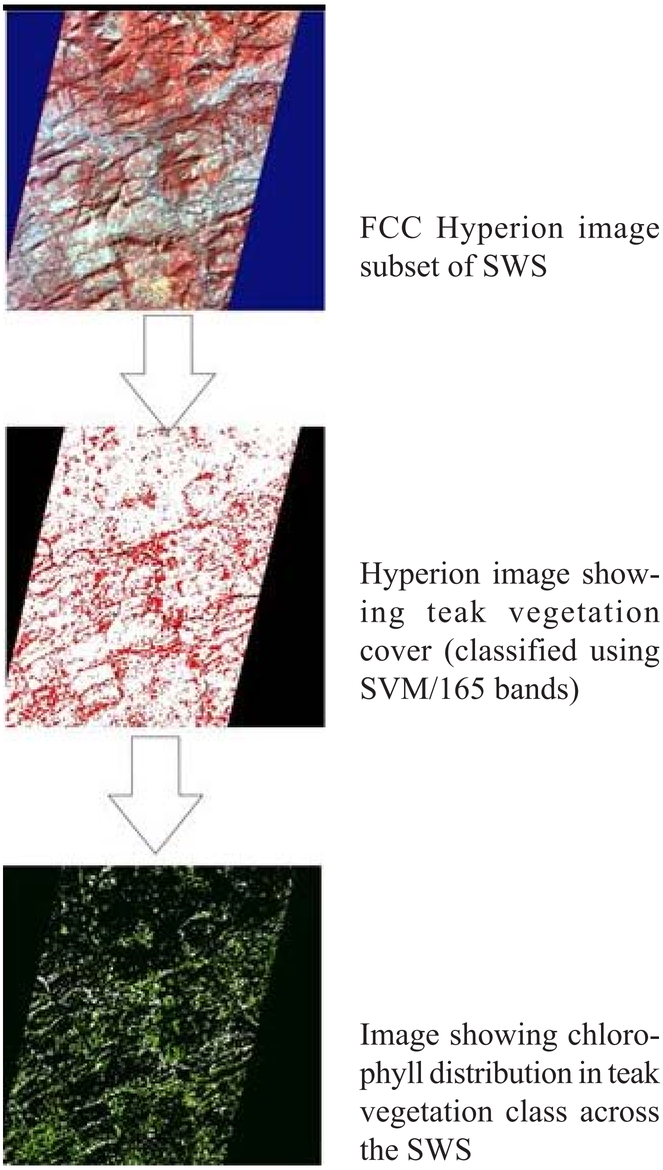

Figure 9. Development of chlorophyll map of teak vegetation covers of SWS

Table 2. Comparison of best performing developed index with other indices.

Developed indices	Lowest %RMSE (per mean value)	Reference
SR 599/1134	30.00	Present study
SR743/692	16.57	Vyas et al. 2013
MCARI/OSAVI 750,705	30.53	Wu et al. 2010
ND 925/710	17.33	le Maire et al. 2009
ND 1141/1150	40.12	Darvishzadeh et al.2008
SR 753/710	19.37	Zarco-Tejada et al. 2004
integral 400–700 nm	32.98	le Maire et al. 2004
TVI	42.32	le Maire et al. 2004

CONCLUSIONS

Present study was able to ascertain the potential of Hyperion (EO-1) data for estimation and mapping of chlorophyll in senescent Teak vegetation covers. SR 599/1134 gave good results for estimation of low amount of chlorophyll per unit area. Chlorophyll index developed here is a very proficient marker for evaluating the healthy status of important tropical tree species such as Teak. Ratios developed here can be tested for Teak covers spread across the tropical regions with similar environmental conditions.

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