Prediction of Prime Wavelengths for the Estimation of Age Based Water Requirement of Arecanut Cropby Hyperspectral Data and VIP

Bhojaraja B E, AmbaShetty, M K Nagaraj

Abstract*: In the world *India is the highest producer and consumer of Arecanut. Also it is widely grown plantation crop in the coastal regions as well other parts of Karnataka. It has a great commercial value both in terms of export potential and revenue generation to the government. The crop sustains for a longer decades and demands huge amount of irrigation water throughout its life span. Assessment of exact amount of crop water requirement in different stages of the plant growth reduces the excessive irrigation. It increases crop yield thereby conserves both ground and surface water. The study targets to identify important wavelengths to predict age based crop water requirement. For this a small portion of the Channagiritaluk is considered for the study. The methodology adopted in this study uses the Hyperspectral data for age based classification of Arecanut crop to map its corresponding water requirement using NDVI based K_C method. From the map pixel wise age based crop water requirement values were extractedand regressed with the corresponding spectral signatures from pre-processed satellite imagery. The PLSR model yielded a coefficient of determination of 0.98. The output of PLSR model results were used in VIP. Total of eight wavelengths, spanning across VNIR and SWIR regions were identified as significant in modeling the ACWR these were 1043, 1053, 1033, 1083, 1023, 1013, 1104, and 854nm. The identified wavelengths are useful to develop a model to estimate the water demand of the study area. The study helps for optimized planning of the water resources.

Keywords—Age based Crop water requirement; Classification; Hyperspectra; PSLR; VIP.

I. INTRODUCTION

Arecanut (Areca catechu L.) is one of the major plantation crop in the world;it is predominantly grown in India by small and medium farm holders. This commercial crop is profitableto growers and plays an important role in improving economy of the country, in terms of export, generation of employment thereby poverty mitigation, especially in rural sector.

It is also a significant cash crop in the Western Ghats, East Coast and North Eastern regions of India. Over seven million farmer families are directly dependent on Arecanut farming and more than 60 million people indirectly depend on Arecanut for their livelihood as labor in Arecanut gardens.

It is grown in India, and adjacent countries. In the world India is the highest producer and consumer of Arecanut, accounts for about 57 percent of the world's total production; followed by China; Bangladesh and Myanmar. In India though the production of Arecanut is limited in few states, its marketable production is widely spread all over the country. Particularly in South India

As per Jain Irrigation Systems Ltd. a pioneering micro irrigation industry of India's report, in the year 2000, India is the largest producer of Arecanut in the world. Karnataka is the largest producer as well as major Arecanut growing state in India followed by Kerala and Assam accounting for about 39% of the world's production.

Though the crop is grown over a large area the production per unit area is less. The main reason for this is improper irrigation; Arecanut crop is sensitive to drought. Poor monsoon and improper irrigation facilities generally decrease the yield of Arecanut crop. Also due to lack of technical knowledge on age based crop water requirement either excessive or deficient supplements of water takes place which adversely affect plant's growth. Improving farmers' knowledge on accurate crop water needs helps in optimizing crop productivity as well as water usage. Hence there is a need to study the exact quantity of water required for Arecanut crop based on its age. To compute the crop water requirement integration of technologies will gives the better solution. An integrated approach in crop management system incorporates several technologies. They are; Global Positioning System (GPS), Geographical Information System (GIS), yield monitor, variable rate technology and remote sensing. A small portion of Arecanut crop abundant area has been considered for the study.

II. LOCATION AND CHARACTERISTICS OF THE STUDY AREA

The Chennagiritaluk in Davangere district of Karnataka, locally identified as the 'land of Arecanut' owing to the abundance of Arecanut plantationsselected for the study. It lies between 13º 57 ' 00 " and 14º 01 ' 45 " N latitude and 75º 57 ' 15 " and 75º 59 '15 " E longitude spread over an area covering of 3,175.2 hectares (31.752 sq. km). Several major villages such as Vaddanahal, Pandomatti and Honnebagi are rapidly developing in this region. Figure 1 shows location map of the Hyperion imagery corresponding to January month of 2014; it can be observed that the continued existences of only irrigated plantation crops are predominant in the image.

Revised Manuscript Received on July 06, 2019.

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The average elevation of Chennagiri is around 660 m above Mean Sea Leveland it is significantly flat terrain. The temperature ranges between 17 to about 40° C and is a relatively dry with humidity of around 18%. The region is considered as semi-arid though it receives an average annual rainfall of 808 mm. The population of the ChannagiriTaluk is around 3 lakhs with majority of population earning their livelihood from Arecanut plantation. Ground water is the major source of irrigation and drip irrigation is practiced throughout the study area. The Arecanut crop farming in this region currently involves addition of tank silt dredged from ponds followed by drip irrigation practiced generally in the form of flooding. Arecanut variety grown here is called "Chennagiri local", which is a tall variety with medium yield. Plants are spaced at an average distance of 8 ft. and in some plots to prevent from bright sun during summer intercropping method were practiced where banana plants were grown in between juvenile Arecanut plants. Majority of the crop is harvested tender, before the fruits are ripened for production of red supari.

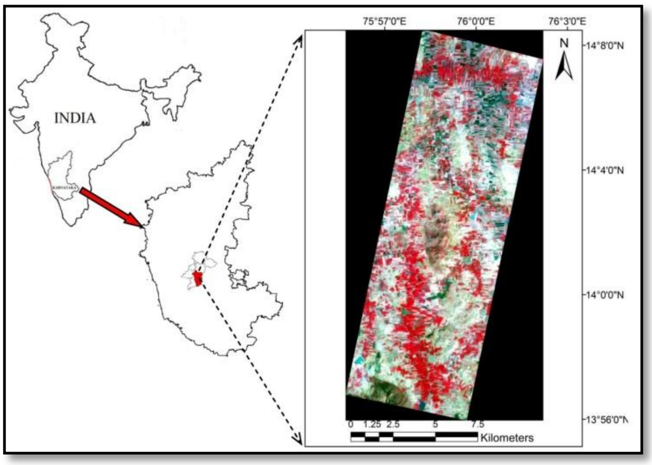

Fig. 1 Location of Arecanut plantation region on Hyperion image

III. SELECTION OF THE STUDY AREA

India is highest producer as well as consumer of Arecanut. Karnataka State alone contributes about 50% of total India's Arecanut production. In Karnataka majority of Arecanut is produced from Shivamogga district, Davanagere district and some parts of coastal zone. The coastal zone of Karnataka is locally known as traditional belt of Arecanut (Kundapura, Udupi and Mangaluru). Due to high commercial value farmers started growing this crop in Chikkamangulu and some part of Shivamogga districts and gradually this crop has spreads to Davanagere district and also in major portions of Karnataka. The ChennagiriTaluk of Davanagere district is locally known as 'Land of Arecanut' because of abundance of spread out of this commercial crop. Though Chennagiritaluk receives less rainfall, this cash crop is grown under irrigation. Major portion of irrigation is from 'Shanthisagar' known as world's second largest pond. Hence there is no strict rule for cropping pattern. Due to high commercial value almost every farmer is growing this crop for their livelihood.

Most of the farmers are small farm holders with less than 10 acres of land. Generally holding sizes vary from 1 to 100 acres and each individual planter practices different farming method. Farmers were adding tank silt lifted from nearby ponds followed by drip irrigation. There are no proper drainage systems to drain off extra irrigated water. The soil type is sandy or red loamy and on top of this added tank silt which gradually settles down and forms an impermeable layer thereby reducing the air voids. This blocks the entry of air and also reduction in hydraulic conductivity which ceases the root development. In summer due to shortage of water the added tank slit gets dry, which damages the plant's root. To overcome this problem, farmers continuously irrigate their farm fields; this causes water stagnation which increases pH value thus soil salinity takes place which causes damage to the plants. Figure 2 show the continuously irrigated water stagnated Arecanut farm.

Fig. 2 Continuously irrigated water stagnated plot.

In coastal Karnataka, in spite of soil being lateritic with high hydraulic conductivity (K) value they practice drainage in between two rows of Arecanut plantations. This acts as drainage gallery in rainy season to drain off excess rain water and the same acts as drowning gallery in summer. The fallen Arecanut leaves were cut in to small pieces and dumped in this gallery which acts as organic manure also prevents water loss from the soil. This practice is not followed in the Chennagiri region and even there is no cultivation practices followed inside the Arecanut plantations. Consolidation of silt spread in the farms causes 'reduction of hydraulic conductivity. Figure 3 shows the non-cultivated, water stressed Arecanut plot. Due to these reasons numbers of diseases are playing an adverse effect on yield of the crops.

Fig.3 Water stressed Arecanut plot.

Though Chennagiritaluk is known as land of Arecanut for its large spread of Arecanut gardens, the productivity is not up to the mark. If there is a proper maintenance and management of this crop, definitely there will be an increase in yield and good economic growth. It also indirectly reduces the huge amount of ground water exploitation.

For monitoring Arecanut crop with advanced techniques definite methodology was formulated. For analyzing the abundance of cropping pattern, sampling locations were selected.

These samples were unique in nature, consisting large quantity of Arecanut crops only. These Includes crop with varying age groups and diseases affected plots.

IV. OVERVIEW OF METHODOLOGY

Figure 4 shows the overall methodology adopted for the study to achieve the formulated research objective. It describes the step wise procedures of different data sets collection for the study, data pre-processing techniques, image classification methods, statistical techniques and analysis of obtained results followed by conclusions.

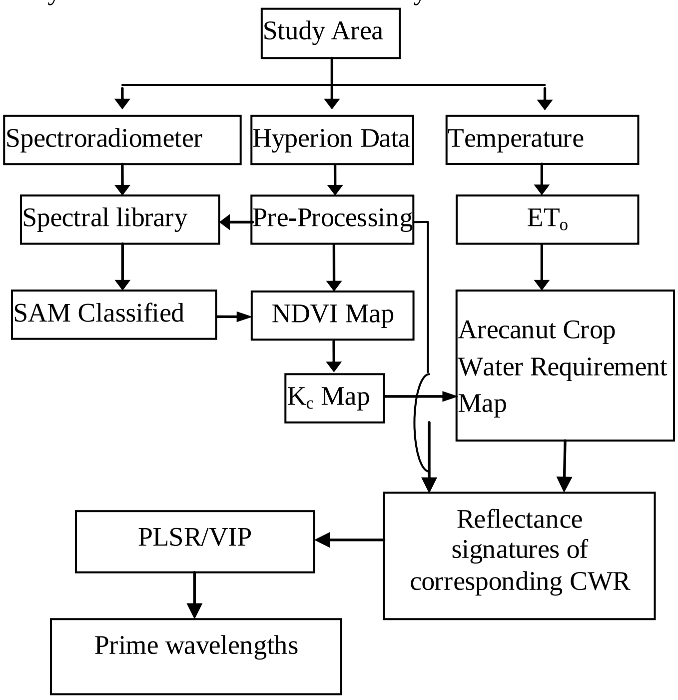

Fig.4 Methodology adopted for the study

A. Data Collection

To accomplish the present work, primarily remotely sensed satellite imagery is obtained from USGS website. For the classification of Hyperion imagery ground truth data is required and this was collected during the field visit. Field data collection includes ASD field spectroradiometer data and Global Positioning System (GPS) data.

B. Spectral analysis using ASD data

The spectral power distributions were measured using Spectroradiometer. For the selection of study area several preliminary field visits were carried out to ensure the inclusion of all age groups of Arecanut crop. After selecting the study area, Arecanut foliage reflectance data of varying age-groups were collected during 10th to 14th February 2014, to build spectral library by grid sampling. The study area was divided into number of grids with a minimum grid size of 1000 m^2 and a representative spectrum was collected from each grid. Tree top reflectance measurements were carried out for representative plots.

C. Partial Least Square Regression (PLSR)

PLS is a bilinear calibration method using data compression by reducing the large number of measured collinear spectral variables to a few non-correlated principal components (PCs). The PCs represent the relevant structural information, which is present in the reflectance measurements to predict the dependent variable by Hansen and Schjoerring [7].

PLS regression uses component projection successively to find latent structures. Visual inspection of score-plots and validation residual variance plots were used to find the optimal number of PCs, so that over-fitting was prevented. In most cases, this procedure can reduce the number of spectral variables to a few independent PCs. The final model predicting ŷi had the following form (Eq. 1):

$$\hat{y}i=b_0+b_{1t1i}+b_{2t2i}+\ldots.+b_{ntni}\ldots\ldots\ldots\ (1)$$

Hence it is found to be appropriate to determine combination of wavelengths to build a model to assess Arecanut crop water demand. Partial Least Squares (PLS) regression is a multivariate analysis technique used in cases where there are a large number of independent variables or predictors and these independent variables are highly collinear (Wold et al. 2001). The PLS method reduces the entire reflectance spectra to a small number of relevant factors and regresses them to the dependent variable, Gomez et al. [5].

A number of variants of PLS exist for estimating the factors and loading matrices for modeling. The most common of these are Non-linear Iterative Partial Least Squares (NIPALS) and Statistically Inspired Modification of PLS (SIMPLS) algorithms. This study employed Partial Least Squares regression for modeling the Arecanut crop water requirement from the Hyperion reflectance spectra. The regression was performed in MATLAB®.

It is found to be appropriate to determine combination of wavelengths to build a model to assess Arecanut crop water demand. In the present study X and Y inputs for the PLSR model obtained are crop water requirement values and corresponding spectral signatures from Arecanut crop water requirement map and pre-processed Hyperion imagery pixels respectively.

D. Identification of significant wavelengths

It is necessary that the wavelengths that are relevant for modeling a particular property be identified. This can be carried out either through projection methods, variable selection or a combination of both.

E.VIP scores and β coefficients

The optionally modified output from the PLSR algorithm can be employed to purely identify a subset of important variables.

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The Variable Importance in PLS projections

(VIP) is such a measure to accumulate the importance of each variable j being reflected by w from each component. The VIP measure vj is computed as in equation

$$V_j = \sqrt{P\sum_{a=1}^{A}[(q_a^2\ t_a' t_a(w_{aj}/||w_a||)^2]/\sum_{a=1}^{A}(q_a^2\ t_a' t_a)} \ldots..(3)$$

Where $(waj/\|wa\|)^2$ represents the importance of the j^{th} variable and the variance explained by each component is given by the expression qa^2ta' ta. The vj weights are a measure of the contribution of each variable according to the variance explained by each PLS component, Mehmood et al. [10]. Variable j can be eliminated if vj< u, for some user-defined threshold u ∈ (0, ∞). It is generally accepted that a variable should be selected if vj> 1. Another Variable selection method is to use the vector of regression coefficients (β) which is a single measure of association between each variable and the response. Even in this case, variables having small absolute value of regression coefficients can be eliminated.

The wavelengths that are significant for modeling the crop water requirement from the Hyperion reflectance spectra using PLS regression were identified by setting thresholds for both Variable Importance for Projection (VIP) and the PLS regression coefficients, β. This was implemented in MATLAB®.

V. RESULTS

A. Assessment of Arecanut crop water requirement using PLSR model

In the present study using ACWR map, pixel wise Arecanut crop water requirement values and their corresponding spectral signatures from pre-processed Hyperion imagery were extracted and tabulated. In order to establish relation between the extracted spectral signatures and crop water requirement values, Partial least square Regression (PLSR) technique is adopted since the method is proved to be a robust and commonly used statistical technique. It can also be extended in various directions as PLSR provides an approach to quantitative modeling of often complicated relationships between predictors (X) and response (Y) and that with complex problems often is more realistic than multiple linear regression (MLR) including stepwise selection variants. Hence it is found to be appropriate to determine combination of wavelengths to build a model to assess Arecanut crop water demand. In the present study X and Y inputs for the PLSR model are obtained crop water requirement values and corresponding spectral signatures from Arecanut crop water requirement map and pre-processed Hyperion imagery pixels respectively. In order to establish the relation between thus obtained extracted spectral signatures and crop water requirement values, Partial least square Regression (PLSR) technique is adopted. From ACWR map, pixel wise Arecanut crop water requirement values and their corresponding spectral signatures from pre-processed Hyperion imagery were extracted and tabulated. In order to establish the relation between thus obtained extracted spectral signatures and crop water requirement values, the Partial Least square Regression (PLSR) technique is as follows.

The selected procedure for identifying the calibration and validation sets is the random selection method to ensure that the PLSR model is unbiased. Regression coefficients were obtained from calibration set and then regression was carried out on validation set.

The result from PLS modeling shows its capability of estimation of Arecanut crop water requirement (ACWR). Selection of PLSR factors was carried out by computing estimated mean square error prediction. Number of PLSR factors used for ACWR prediction is Figure 5 (a) & (b) shows the ACWR prediction results and comparatively good prediction is observed.

Calibration dataset yielded an R^2 of 0.98 with RMSE of 0.34. Validation dataset yielded an R^2 of 0.97 with RMSE of 0.83. Higher RMSE may be due to high variability, spatial resolution of Hyperion and small sized scattered fields.

Figure 5 a&b shows the graphical representation of calibration results.

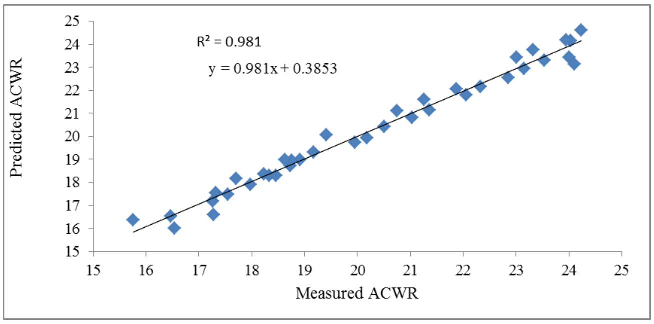

Fig. 5 (a) PLSR for calibration

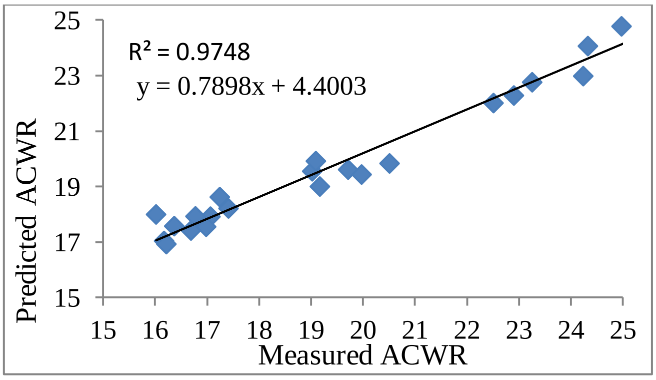

Fig.5 (b) PLSR for validation of ACWR

B. *Arecanut Crop Water Requirement Model (ACWR)*

Based on PLSR b-coefficients with 3 factors the important wavelengths found are 548, 681 and 721 the combination of these wavelengths equation is as follows (Eq.4)

$$Y= (20.26-1.89*\lambda_{548}-2.32*\lambda_{681}+2.36*\lambda_{721})/100 \ldots(4)$$

Where Y is the predicted Arecanut water requirement value in terms of l/day/plant and λ_{548}, λ_{681}, λ_{721} are the reflectance values of corresponding wavelengths. In validation ACWR model with combination of only three wavelengths yielded an R^2 of 0.65. Figure 6 shows the model validation graphical representation.

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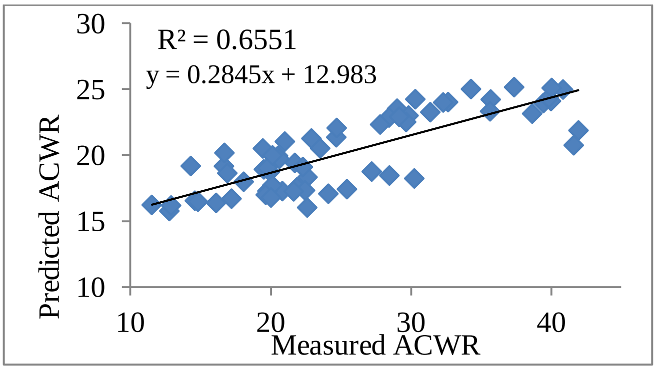

Fig. 6 Results of Model validation.

C. *Selection of Important Variables*

The output from the PLSR algorithm was employed to identify a subset of wavelengths that are significant in predicting the ACWR from spectral reflectance data. For this, both Variable Importance for Projection (VIP) scores and the PLS regression coefficient (β) value were taken as the selection parameters, as observed in similar studies (Mehmood et al. [10], Rossel et al. [5]. This was executed in MATLAB and the codes used are given in the appendix at the end of this report. Wavelengths corresponding to significantly higher VIP scores and β coefficient values were noticed as important from the study undertaken. The graphs representing VIP scores and β coefficient values are illustrated in Figures 7 and 7.1Selection of important variables is very important when there is collinearity in the dataset. This can be achieved by computing Variable Importance for Projection (VIP) and also by considering β-coefficients. VIP is a weighted sum of squares of the PLS weights, with weights calculated from the amount of Y-Variance of each PLS component, Wold et al. [14]. Greater than 1 rule is used as a criterion for variable selection, Chong and Jun, [3].

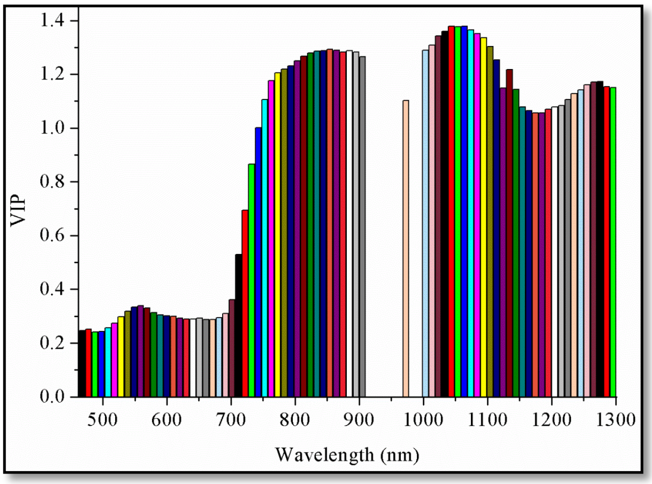

Fig. 7 VIP scores corresponding to wavelengths

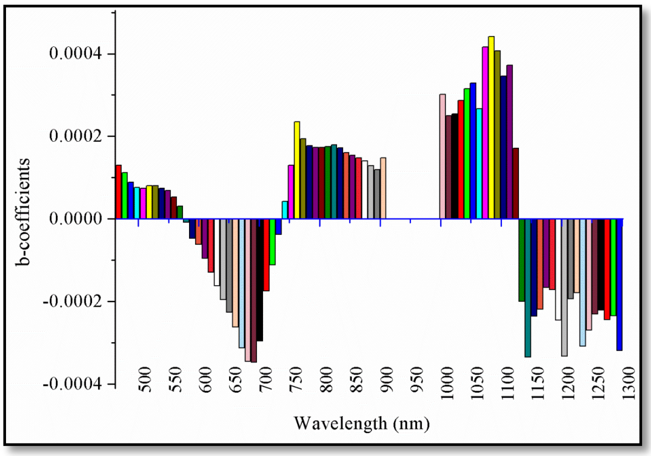

Fig. 7.1 β coefficients corresponding to wavelengths for ACWR

After comparing the VIP scores and β coefficient values, a total of eight wavelengths, spanning across VNIR and SWIR regions were identified as significant in modeling the ACWR these were 1043, 1053, 1033, 1083, 1023, 1013, 1104, and 854nm.

VI. CONCLUSION

The approach of remote sensing using Hyperion image showed it has potential benefit to map Arecanut water requirement map. This study establishes a newer approach to remotely ascertain water consumption by farmers to utilize the available water resources wisely. The study also proposes that the Hyperion coupled with PLSR technique provides a rapid, accurate determination of ACWR. By comparing VIP scores and β coefficient values, a total of eight wavelengths, spanning across VNIR and SWIR regions were identified as significant in modeling the ACWR these were 1043, 1053, 1033, 1083, 1023, 1013, 1104, and 854nm.

REFERENCES

1. Anshu Miglani., Ray, S. S., Pandey, R.,and Parihar, J.S.,(2008). “Evolution of EO-1 Hyperion Data for Agricultural Applications”. J. Indian Soc. Remote Sens.(36)255–266.
2. Chakravortty Somdatta., and Chakrabarti, S. (2011). “Preprocessing of Hyperspectral Data : A Case Study of Henry and Lothian Islands in Sunderban Region, West Bengal, India”. International Journal of Geomatics and Geosciences, (2), 2-1
3. Chong, I. G., and Jun, C. H. (2005). “Performance of some variable selection methods when multicollinearity is present”. Chemometrics and Intelligent Laboratory Systems, 78(1), 103-112.
4. Droogers P and Allen R. G. (2002) “Estimating reference evapotranspiration under inaccurate data conditions.” Irrigation and drainage systems, 16(1), 33-45.
5. Gomez, C., Viscarra Rossel R, A., and McBratney, A, B. (2008). “Soil organic carbon prediction by hyperspectral remote sensing and field vis-NIR spectroscopy: An Australian case study”. Geoderma, 146, 403–411.
6. Gosselin, R., Rodrigue, D., and Duchesne, C. (2010). “A Bootstrap-VIP approach for selecting wavelength intervals in spectral imaging applications”. Chemometrics and Intelligent Laboratory Systems, 100(1), 12-21
7. Hansen P. M., and J. K. Schjoerring. (2003) "Reflectance measurement of canopy biomass and nitrogen status in wheat crops using normalized difference vegetation indices and partial least squares regression." Remote sensing of environment 86, no. 4 :542-553.

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8. Kamble B., Kilic A. and Hubbard K, (2013). "Estimating crop coefficients using remote sensing-based vegetation index". Remote Sensing, 5(4), 1588-1602.
9. Kvalheim, Olav M., (1987)"Maturity determination of organic matter in coals using the methylphenanthrene distribution." Geochimica et Cosmochimica Acta" 51.7: 1883-1888.
10. Mehmood, T., Liland, K. H., Snipen, L., and Saebo, S. (2012). "A review of variable selection methods in partial least squares regression. Chemometrics and Intelligent Laboratory Systems", 118, 62-69.
11. Ramappa B.T (2013). "Economics of Areca nut Cultivation in Karnataka, a Case Study of Shivamogga district". Journal of Agriculture and Veterinary Science 3, 1, 50-59.
12. Song, Shalei, Gong, Wei, Zhu, Bo, Huang,and Xin (2011). "Wavelength selection and spectral discrimination for paddy rice, with laboratory measurements of hyperspectral leaf reflectance". ISPRS Journal of Photogrammetry and Remote Sensing 66, 672–682.
13. Wilson, J. H., Zhang, C., and Kovacs, J. M. (2014). "Separating Crop Species in Northeastern Ontario Using Hyperspectral Data". Remote Sensing, 6(2), 925-945.
14. Wold, S., Sjöström, M., and Eriksson, L. (2001). "PLS-regression: a basic tool of chemometrics". Chemometrics and intelligent laboratory systems, 58(2), 109-130.

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Dr. Nagaraj M.K. is an academician with over 36 years of rich teaching and research experience. He has participated and presented several research papers at State, National and International seminars, conferences organised by various Institutions and Universities of the Country and abroad. He also has several research publications to his credit. He was sent on deputation to AIT, Bangkok by Faculty Secondment Program, Government of India. He has visited Flinders University, Adelaide, Australia for research interaction in the area of ground water engineering. He has guided many scholars for their M.Tech Thesis and Ph.D. He has worked on several R & D projects in the capacity of Chief Investigator and also as Coordinator. He is a member of various professional bodies and has undertaken several consultancy works. He has worked at NITK, Surathkal in various capacities and has served in the board of various academic organisations.

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