Above Ground Biomass Estimation and Mapping using Satellite Remote Sensing and in Situ Measurements in Chichawatni Plantation Site in Pakistan

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Abstract **– In the previous years and decades, large quantity of carbon has contributed to globcal climate change and ecosystem disturbance because of anthropogenic activities. To study the carbon cycle, forest biomass is an important element as a carbon sink, and it is also a chief factor in forest health and climate change. Satellite remote sensing is a useful approach for the monitoring of forest resources and biomass estimation. This study investigates the accuracies of spatially estimated and mapped Above Ground Biomass (AGB) of three main species i.e. "*Dalbergia sissoo*", "*Eucalyptus camaldulensis*" and "*Bombax ceiba*" in Chichawatni Forest, Punjab, Pakistan. In this work, AGB modelling and mapping was performed through six different spectral indices, NDVI "Normalized Difference Vegetation Index", TNDVI "Transformed Normalized Difference Vegetation Index", SAVI "Soil Adjusted Vegetation Index", SARVI "Soil and Atmospherically Resistant Vegetation Index", Square root of (Infrared/Red) "SQRT(IR/R", MSR "Modified Simple Ratio") calculated from Pleiades satellite data with a spatial resolution of 2 m. Simple linear and multiple-linear regression models were developed across the field based AGB and spectral indices derived from satellite imagery.Firstly for "*Dalbergia sissoo*", and "*Bombax ceiba*", reasonable accuracy (R^2 values of 0.65 and 0.88, respectively) for AGB biomass estimation was achieved by combining different indices from Pleaids optical sensor. Using the single indices, only moderate performance (R^2 = 0.52 for "*Dalbergia sissoo*" and 0.87 for "*Bombax ceiba*") was observed from the spectral reflectance of the Pleiades satellite data. Secondly for Eucalyptus reasonable accuracy (R^2 = 0.73) was achieved either using single or combining different spectral indices. These developed models for three tree species future can be utilized for reliable estimation and assessment of the changes in biomass. The study will be helpful for "Sustainable Forest Management" and preserve biomass/carbon in the performance based payment mechanism in forest ecosystem.**

Keywords: **Above Ground Biomass (AGB), Pleiades satellite data, Spectral indices, Chichawatni plantation and Sustainable forest management**

I. INTRODUCTION

The large quantity of carbon coming from anthropogenic activities has contributed towards global climate change in the recent decades [1]. Considering the natural and fundamental position within the functioning of the biosphere via regulating worldwide carbon cycle, forests obviously reduce carbon content in the atmosphere notably. Regardless of the devastating effects of worldwide climate change, forests have the ability to stabilize the atmospheric carbon dioxide concentrations thus mitigating the worldwide warming and the climate change. About 2-4 Gt Carbon of atmosphere may be sequestered by forests yearly [2][3]. Land cover and density of forest trees had been substantially lowering everywhere in the world because of remarkable growth of population and removal of forests stand for use of wood or agricultural practicing, fire wood and range land activities that led to decline of biomass [2]. Trees are important part of "forest ecosystem" that play vital role in "global carbon cycle" [4]. About 650 billion tones carbon stock present in the existing forest stands, 45% is present in soil, 44 % in the dry biomass, and remaining 11 % in the forest floor and dead wood of forest land [5].

To understand the changes in climate globally it is necessary to know about measurements of various parameters of forests like volume, AGB (Above Ground Biomass) and carbon content in forests etc. [6][7]. For the "sustainable and effective management" of forests, frequent monitoring of AGB is a crucial venture. Overall, the correct and precise mapping of change in land cover is required for calculating the rate of deforestation to support the monitoring of biomass change with the passage of time. So, appraisal of biomass and carbon in atmosphere are both necessary.

Initiatives like REDD and REDD+ "Reducing Emissions from Deforestation and Forest Degradation" also depend on accurate & precise estimation of AGB [8]. "REDD" plus includes carbon credit and other incentives for amending climate change by decreasing deforestation and wooded area degradation, conservation, and enhancement of carbon stocks. The nations that take part in scheme of "REDD+" have a demand to provide correct carbon stock estimates or any change in it. Pakistan number is in top ten in the Climate Risk Index. Due to that reason a special attention is required to recognize the actual status of forests of Pakistan and also get significance at policy level. Pakistan has become the fifth country in the world that undertakes the comprehensive legislation on Climate Change by passing Pakistan Climate Change Bill 2017. Due to being signatory of UNFCCC (United Nations Framework Convention on Climate Change) and Kyoto Protocol, it needs to estimate the correct and precise calculation of net discharge of greenhouses gasses and rate of carbon storage with time. In Pakistan, carbon budgeting of forests is in initial level that needs greater research in the discipline of geospatial technologies.

Limited studies have been carried out in different forests of Pakistan regarding biomass and carbon stock estimation. Mostly these studies are based on either volume calculation or Biomass Expansion Factor (BEF) method or already developed allometric equations by different National/ International authors. Some researcher use allometric equation develop through destructive sampling method for estimation of biomass in different areas of Pakistan. Few studies are also carried out based upon remote sensing method [9]. For a more detailed summary of these studies, we refer to Baig et al. (2017) [9] and Ismail et al. (2018) [10]. A recent study based on spectral indices derived from satellite imagery for appraisal of carbon stock of different scrub species of KPK, Pakistan was carried out by Ali, A et al. [10].

It is essential to know about the available low-cost forest AGB estimation strategies [11][12]. Conventional methods for inventory are more precise for estimation of biomass however they require more time, money and labor work. Through this method the spatial distribution of biomass in larger areas can't be possible. Hence to clear up this hassle, "remote sensing" techniques are easy and quick approach with sufficient sample plots data for biomass estimation for a large region and monitoring purposes. The remote sensing images have been utilized by a great number of researchers from the world to monitor the above ground biomass of forests.

Forest biomass can be estimated through remote sensing by finding out the correlation among the spectral response of passive optical remote sensing and field sample plots values[13][14]. A great number of studies relating to estimation of above ground biomass have employed optical remote sensing due to its easy accessibility and affordability [15][16][2]. Vegetation biomass is a comprehensive variable, this is associated with many factors which includes vegetation stand structure, vegetation density and vegetation species composition.

VI (Vegetation Indices) are spectral indices, mixtures of reflectance of surface at two or more wavelengths developed to represent a specific property of flora/vegetation. These are developed by utilizing the reflectance characteristics of plants. Each Vegetation Index is considered to represent a specific vegetation feature. Spectral indices derived from optical sensor imageries are extensively utilized for the assessment of biomass. More than 150 vegetation indices had been published in scientific research, but only some have strong biophysical basis or has been systematically examined [17]. Some scientists utilized linear regression model along or with log transformation to develop relation between field biomass and satellite data. [18],while others have used multiple regression with or without stepwise selection [19][20]. Nonlinear regression [21], artificial neural networks [22][23], semi empirical model [24], and non-parametric estimation techniques like "K-Nearest Neighbor" and "k-Means Clustering have also been broadly utilized.

With this background, the objective of this study is; for three tree species in the study site Chichawatni Irrigated Plantation, i.e. *Dalbergia sissoo* (Shisham), *Eucalyptus camaldulensis* (Sufeda) and *Bombax ceiba* (Semal), the generation of AGB regression models by optical spectral indices and field-calculated biomass to assess and map carbon stocks in the study region.

II. STUDY AREA

Chichawatni is a manmade irrigated plantation established in the subcontinent to support steam engines of railways and other infrastructure. These are still main source of commercial timber and firewood in Pakistan. Chichawatni Irrigated Plantation is situated in southern region of Punjab at latitudes 30.531042° N and longitudes 72.636604° E and at an altitude of 153.6 m to 163.7 m above sea level. According to Punjab Government Notification No. 4178 dated 28 Feb 1917, this plantation was declared as Chichawatni Reserved Forest with an area of 4669.11 hectares (Figure 1). Weather of the area is mostly dry. Summers are very hot on the other hand the winters are small but severe. The temperature fluctuates from 0 ^{0}C to 49 ^{0}C under shadow throughout the year. The annual rainfall ranged from 43 mm to 516.5 mm from July 2004 to December 2013. Some details about the study area are also given in [9].

Chichawatni Forest was initially "dry tropical rakh" and contains vegetation of *"Salvadora oleodes"* (Wan), "*Tamarix aphylla" (*Frash) and "*Prosopis spicigera"* (Jand) etc. The prevailing dense stock contains of predominantly "*Dalbergia sissoo"* (Shisham), "Eucalyptus *camaldulensis"* (Sufeda), "*Bombax ceiba"* (Semal) along with other scattered species i.e "*Acacia nilotica*" (kikar), "*Morus alba*" (Toot) etc.

III. MATERIAL

In this study, we used field samples for the calculation of AGB of three selected tree species and Pleiades 2m multi-spectral satellite imagery. The details of material is given in the following sections;

Field data

Chichawatni Irrigated Plantation is manmade Forest and is managed by the Divisional Forest Officer (DFO) Chichawatni, Punjab Forest Department. The role of field data collection cannot be ignored for accurate appraisal of biomass through developing a relation between field data and satellite data. For field data collection, field campaigns were carried out from 2015-2017. During the field survey, biophysical features, i.e. diameter at breast height (DBH) and height of tree were measured for three species i.e "*Dalbergia sissoo"* (Shisham), "*Eucalyptus camaldulensis"* (Sufeda) and "*Bombax ceiba"* (Semal).

A survey map for field visit was prepared from working plan map which was received from Divisional Forest Officer (DFO) Chichawatni. In this research three main species were considered, i.e., "*Dalbergia sissoo", "Eucalptus camaldulensis" and "Bombax ceiba"*, with respectively 24, 26, 22 sample plots measured for each. The sample plot of square shape with size 20m x 20m was used in this research. The method used for selection of sample plot was "random sample" method while trying to include all individual trees greater than 3 cm diameter to be measured. Tree diameter was measured using caliper and tree height was measured with clinometers. Field data collection forms were used to record field information.

Pleiades satellite data

A "high resolution multispectral" image of satellite Pleiades was used in this research, acquired in May 2015. The multispectral image of Pleiades a spatial resolution of 2 m and consists of four wavelength bands: Blue "Band1 430-550 nm", Green "Band 2; 490-610 nm", Red "Band 3; 600-720 nm", Near Infrared "Band 4; 750-950 nm".

This image was corrected atmospherically and radiometrically and resulted in values of surface reflectance. There are different methods to make remote sensing data correct atmospherically [25]. Due to absence of physical atmospheric data, "Dark Object Subtraction" (DOS) technique was employed the atmospheric correction.

In this method by assuming that dark objects exist in each image scene, the "radiometric correction" should be possible via removing the dark objects pixel value from all pixels of satellite image. Through "Dark Object Subtraction" method, simple atmospheric scattering were corrected as a result of atmospheric effects, because this technique is unproductive in composite atmospheric absorption effect.

IV. METHODOLOGY

The figure 2 shows the flow chart of methodology utilized in exploring and processing field surveyed and optical remotely sensed datasets for AGB estimation over the study site.

Analysis of field data

The "allometric equations" were established for different tree species by Afzal and Akhter (2011) [26] for Chichawatni plantation. The allometric relationship of DBH and AGB for "*Dalbergia sissoo"* (Shisham), "*Eucalyptus camaldulensis"* (Sufeda) and "*Bombax ceiba"* (Semal) are given in Eq. 1, 2 and 3 respectively:

$$AGB = 0.01697 \times D^{2.9795} \quad \text{Eq. (1)}$$

$$AGB = 0.0755 \times D^{2.6235} \quad \text{Eq. (2)}$$

$$AGB = 0.0136 \times D^{2.948} \quad \text{Eq. (3)}$$

where D is the DBH in cm, and the numbers represent the determined regression coefficients. In this study, the biomass of each tree in each plot was calculated using the above-mentioned allometric model developed by [26]. Tree AGB was computed for all trees in each plot through allometric equation whereas plot biomass was computed by taking the summing up the biomass of all trees in each plot.

By utilizing the Eq (4) the AGB calculated at plot level that are in Kg were converted into ton.

$$AGB\ (tons) = AGB\ (kg)/1000 \quad \text{Eq. (4)}$$

The AGB (ton) at plot level was spatially up scaled to ton/ha by using spatial scaling factor. This factor was calculated from entire area of sample plot to make simple the computational method and to follow standard unit for biomass used in various studies. The equation (5) was utilized for this conversion

$$AGB\ (ton/ha) = AGB\ (ton) * F \quad \text{Eq. (5)}$$

where F is scaling factor. In this study, the scaling factor is 25 according to the plot size of 400 m^2.

Spectral indices from Pleiades satellite data

In this research six different spectral vegetation indices were derived from Pleiades satellite data: "Normalized Difference Vegetation Index" (NDVI), "Transformed Normalized Difference Vegetation Index" (TNDVI), "Soil Adjusted Vegetation Index" (SAVI), "Soil and Atmospherically Resistant Vegetation Index" (SARVI), "Square root of Infrared and Red spectral bands" (SQRT(IR/R), "Modified Simple Ratio" (MSR). The indices values were derived by extracting the mean values of image pixels within each of the 24, 26, 22 biomass plots of "*Dalbergia sissoo"* (Shisham), "*Eucalyptus camaldulensis"* (Sufeda) and "*Bombax ceiba"* (Semal) respectively (Figure 1).

AGB modeling and validation

Regression models, "Linear" and "Multiple-linear", were developed to create relationship between satellite images derived spectral indices and field based AGB. The AGB was used as a dependent variable while indices were used as independent variables.

The evaluation of performance of regression model was carried out through the value of "Coefficient of determination" (R^2) as this measure is a standard measure to evaluate a regression model. In addition to basic statistics of regression model fitness, 12, 9 and 13 independent validation plots for "*Dalbergia sissoo"* (Shisham), "*Eucalyptus camaldulensis"* (Sufeda) and "*Bombax ceiba"* (Semal) were utilized for models validation respectively.

V. RESULTS

The AGB in terms of quantitative assessment and its forest mapping through remote sensing methods is vital and challenging. The further verification by ground truthing up to reasonable sample numbers is very important for acceptable consistency and reliability of results.

This study investigated the usability by using the single indices or combining different indices of optical satellite imagery for biomass estimation of vegetation for specific species at specific site i.e. irrigated plantation site for "*Dalbergia sissoo", "Bombax ceiba'* and "*Eucalyptus camadulensis"*.

AGB of Dalbergia sissoo (Shisham)

The biomass in the 24 field plots was found in the range of 04 to 141 t/ha and it covers all tree sizes of the plantation. In the AGB modeling process, the AGB values of total 24 field plots were used as the dependent variable, and the spectral indices values were used as independent variables. Biomass model was also generated by combining the different indices which shows good result as compared to single indices in case of *Dalbergia sissoo* (Shisham). Table 1 summarizes the output of the regression analysis between field based calculated AGB and vegetation indices of "*Dalbergia sissoo"* (Shisham).

The best estimates of biomass of *Dalbergia sissoo* (Shisham) using single indices from Pleiades as well as different combination of indices produced only 69% usable accuracy. From the individual indices the best result (R^2=0.58) was obtained from SQRT index followed by NDVI (best R^2=0.519), SAVI (best R^2=0.50), TNDVI (best R^2= 0.48). SARVI and MSR performed substantially worse (best R^2=0.42 and 0.38 respectively). The performance of the model (R^2) increased from 0.58 to 0.690 by combining different indices as shown in table 1.

Accuracy assessment for all AGB models were checked with total 12 field sample plots by applying the linear regression analysis of each biomass maps. The results shows that the biomass model no 8, 13 and 17 derived from the spectral indices of satellite sensor represent good accuracy ($R^{2=}$ 0.65,0.65, and 0.638 respectively), as shown in table 1 and Figures 3 and 6.

AGB of Eucalyptus camaldulensis (Sufeda)

The biomass in the 26 field plots were found in the range of 09 to 451 t/ha and it covers all tree sizes of the plantation. Table 2 summarizes the output of the regression models between "AGB" and "vegetation indices" of "*Eucalyptus camaldulensis"* (Sufeda).

The best estimates of biomass of *Eucalyptus camaldulensis* (Sufeda) using single indices from Pleiades, as well as different combination of indices produced 82% usable accuracy. From the individual indices the best result (R^2 =0.82) was obtained from NDVI, SAVI, TNDV indices followed by SQRT (best R^2=0.80), SARVI (best R^2=0.72). MSR performed substantially worse (best R^2=0.49). The performance of the model (R^2= 0.82) remained same by using combining different indices as shown in table 2. Accuracy assessment for all AGB models were checked with total 9 field sample plots by applying the linear regression analysis of each biomass maps. The results shows that the biomass model no 01, 05 and 09 derived from the spectral indices of satellite sensor represent good accuracy ($R^{2=}$ 0.73,0.631, and 0.637 respectively) as shown in table 2 and Figures 4 and 7.

AGB of Bombax ceiba (Semal)

The biomass in the 22 field plots were found in the range of 18 to 678 t/ha and it covers all tree sizes of the plantation. Table 3 summarizes the outcome of the regression model sbetween "AGB" and "Vegetation indices" of "*Bombax ceiba"* (Semal).

The best estimates of biomass of "*Bombax ceiba"* (Semal) using single indices from Pleiades, as well as different combination of indices produced only 79% usable accuracy. From the individual indices the best result (R^2 =0.76) was obtained from SQRT index followed by NDVI and SAVI (best R^2=0.74), TNDVI (best R^2=0.73), MSR (best R^2= 0.69). SARVI performed substantially low (best R^2=0.61). The performance of the model (R^2) slightly increased from 0.76 to 0.79 by using combining different indices as shown in table 3. Accuracy assessment for all AGB models was checked with total 13 field sample plots by applying the linear regression analysis of each biomass maps. The results shows that the biomass model no 6, 10 and 16 derived from the spectral indices of satellite sensor represent good accuracy ($R^{2=}$ 0.877, 0.884, and 0.862 respectively) as shown in table 3 and Figures 5 and 8.

VI. DISCUSSION

In Pakistan, very little generic work has been done by using remote sensing datasets for forest AGB assessment having certain limitations for trees and area [4][27][28][29]. This study investigated the remote sensing data usability by using the single indices or combining different indices of optical satellite imagery for biomass estimation of vegetation for specific species at specific site i.e. Irrigated plantation site for *Dalbergia sissoo, Bombax ceiba* and *Eucalyptus camadulensis*.

Basit et al. (2013) [30] explained that the irrigated plantations in Punjab consist of over 23.55% of the forest area, which is 0.720 % of the whole geographical part of the Punjab Province in Pakistan. Irrigated plantations are playing major roles either by providing protection in terms of carbon sink to control global warming and climatic changes or by yield of wood, fire wood and other forest products for commercial forestry objectives. In addition, eco-tourism is emerging as environmental friendly activity. The modern concepts are revealed for irrigated plantations by having vital biomass and carbon sinks to mitigate climatic/environmental issues. At present, the drastic climatic catastrophes of drought, low crop productivity, alarming water crisis, floods and land nutrient degradation are becoming more prominent phenomena. These conditions has revealed clearly the important and mitigation role of irrigated plantations for Pakistan specifically and whole world in general.

For *Dalbergia sissoo*, and *Bombax cieba*, reasonable accuracy (R^2 =0 .65 for *Dalbergia sissoo* and 0.88 for *Bombax ceiba*) for AGB biomass estimation was achieved by combining different indices from Pleiades optical sensor. Using the single indices, only moderate performance (R^2 =0.52 for *Dalbergia sissoo* and 0.87 for *Bombax cieba*) was observed from the spectral reflectance of the Pleiades satellite data. For Eucalyptus reasonable accuracy R^2 = 0.73 was achieved either using single or combining different indices.

Implementation of one model developed for any other species or site is a major limitation of transferability of developed models, which may not be workable for any other species, either due to change in edaphic, climatic variations and phenology of trees or model own restrictions and dataset [20]. The variation in methods used for field data collection i.e., frequency, number and size of sampling plots and spatial dataset have certain restrictions for transfer of developed model and its appropriate use for changed species and conditions. In the same region having similarity of edaphic and climatic conditions, the models developed in one part may work in other part within such regions. The restrictions encountered for transfer of model may be due to handling / processing methods of spatial dataset and field measurements variations.

Nevertheless of aforementioned limitations, this study model is established on three species in the same study area first time to derive further quantitative estimates over different forest species and their comparison with using customary approaches of either "allometry" or "destructive sampling" [26][31]; however, models developed in this study will be suitable for monitoring AGB with remotely sensed parameters. This model in future will be a good tool for reliable estimation and assessment of the changes in biomass of different vegetation species. The study will be helpful for "sustainable forest management" and preserve biomass in the ecosystem either through REDD+ projects and other development schemes. This effort will be a base line for future works, and outcomes of this effort may be useful for carbon conservation and fixation initiatives. By adding the texture feature which is spatial characteristic of images, and has already shown potential for biomass appraisal, the modeling accuracy for AGB can be improved. [32][33] [34].

VII. CONCLUSION

In Pakistan, very little generic work has been done by using satellite remote sensing data for AGB appraisal with certain limitations of tree species and sites. The development of initial base line regarding AGB estimation using Pleiades optical remote sensing technique is salient outcome of this research. This study investigated the remote sensing data usability by using the single index or combining different spectral indices of optical satellite imagery for AGB estimation of three tree species "*Dalbergia sissoo", "Bombax ceiba"* and "*Eucalyptus camadulensis"*.Based on this research and the developed models for three tree species, the can in the future be utilized for reliable estimation and assessment of the changes in biomass. The study will be helpful for "sustainable forest management" and preserve biomass in the performance based payment mechanism in forest ecosystems.

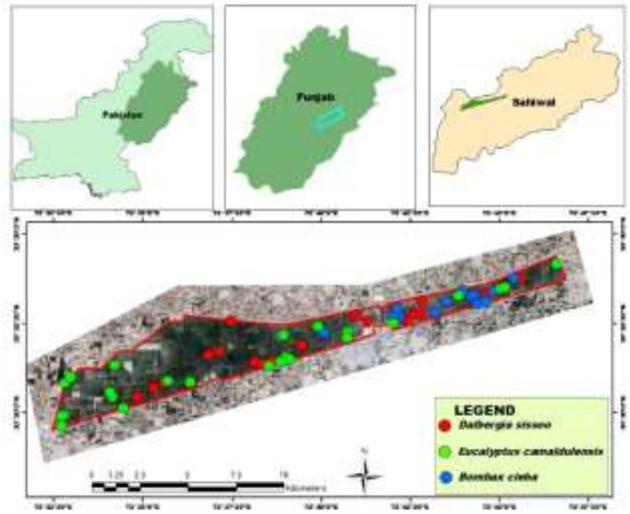

Fig.1. Study area map overlaid with ground sample distribution

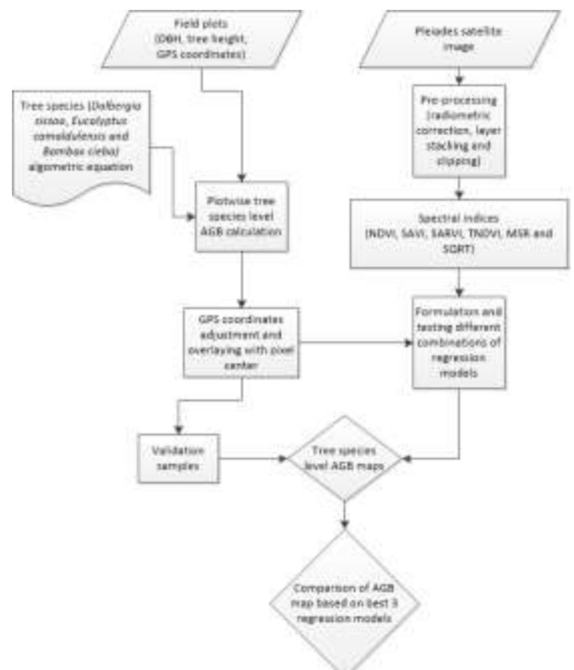

Fig. 2. Methodological flowchart diagram

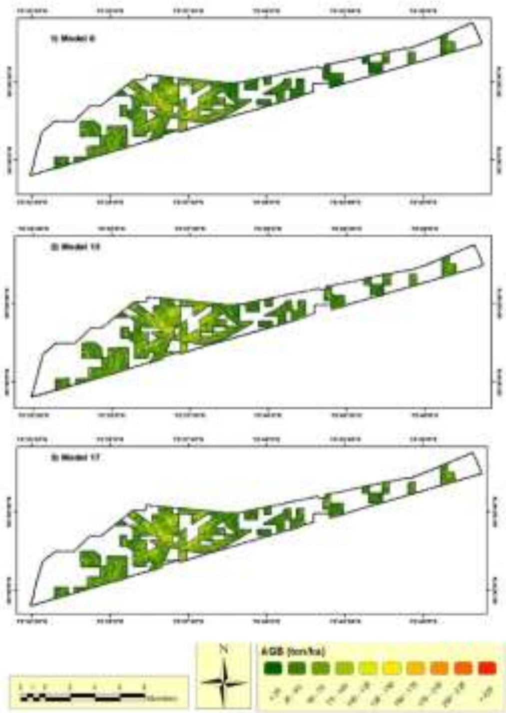

Fig. 3. AGB map of *Dalbergia sissoo* (Shisham) based on best three models

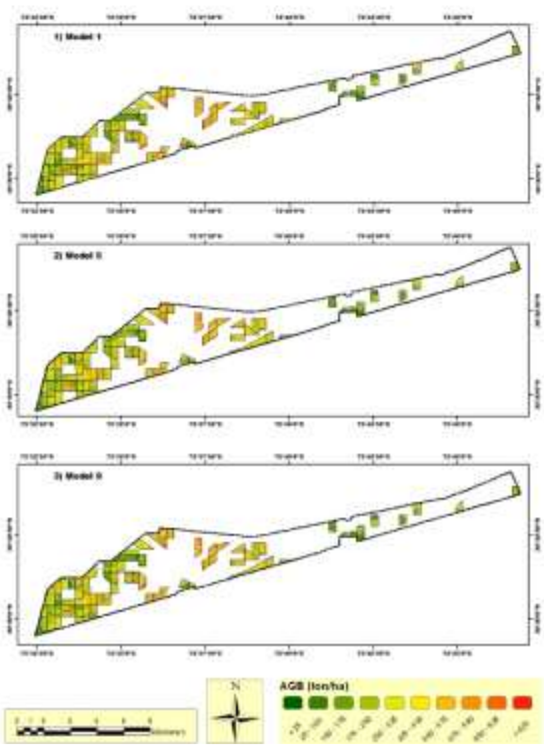

Fig. 4. AGB map of *Eucalyptus camaldulensis (Sufeda)* based on best three models

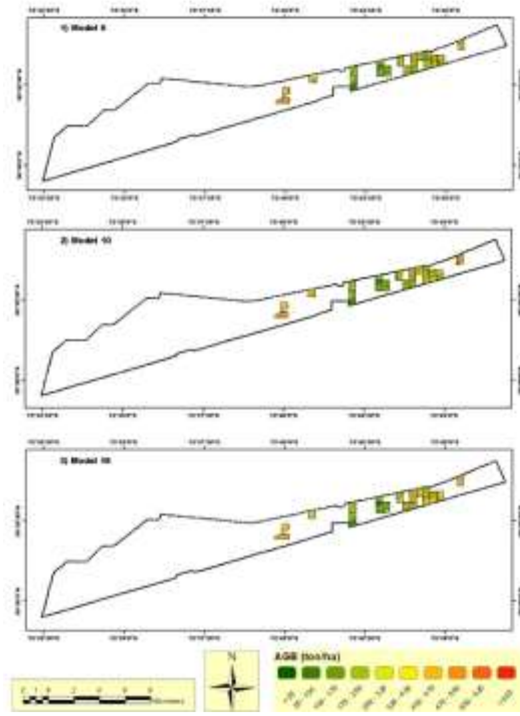

Fig. 5. AGB map of *Bombax ceiba (Semal)* based on best three models

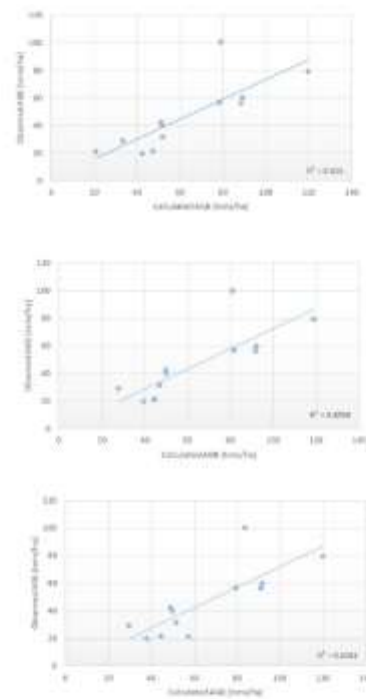

Fig. 6. Validation plot of model 8, 13 and 17 between observed and calculated value AGB of Shisham (*Dalbergia sissoo*)

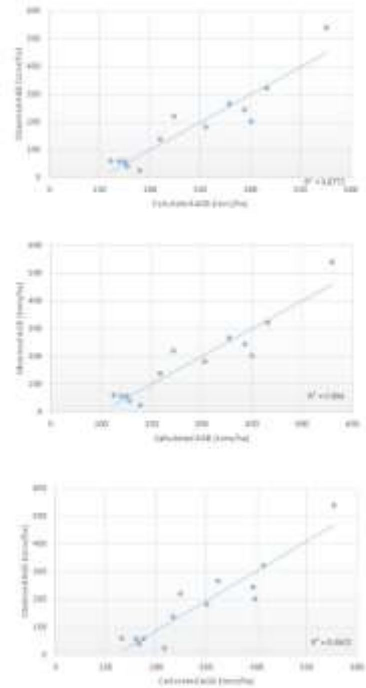

Fig. 7. Validation plot of model 1, 5 and 9 between observed and calculated value AGB of Shisham (*Dalbergia sissoo*)

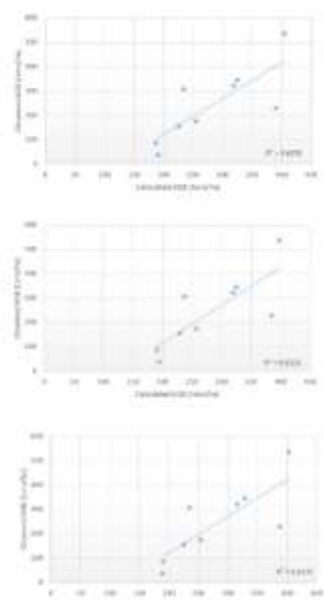

Fig 8. Validation plot of model 6, 10 and 18 between observed and calculated value AGB of Shisham (*Dalbergia sissoo*)

TABLE I

REGRESSION MODELS FOR *DALBERGIA SISSOO* (SHISHAM) BETWEEN FIELD MEASURED AGB AND SATELLITE DERIVED VEGETATION INDICES.

Regression Model	Equations	R Square Value	R Square Validation
Model 1	AGB = -16.330 + 144.926* NDVI	0.519	0.465
Model 2	AGB = -15.200 + 95.447* SAVI	0.503	0.465
Model 3	AGB = -18.194 + 156.938* MSR	0.379	0.288
Model 4	AGB = -3.511 + 71.015* SARVI	0.427	0.588
Model 5	AGB = -209.73 + 266.456* TNDVI	0.483	0.430
Model 6	AGB = -74.526 + 73.819* SQRT	0.580	0.520
Model 7	AGB = 109.420 + 154.785* SQRT - 329.29* TNDVI	0.620	0.532
Model 8	AGB = -103.102 - 170.92* MSR + 134.208* SQRT	0.642	0.656
Model 9	AGB = -16.538 + 71.341* MSR + 47.77* SARVI	0.460	0.488
Model 10	AGB = -104.855 - 90.189* NDVI + 116.164* SQRT	0.590	0.511
Model 11	AGB = -16.262 + 137.683* NDVI + 4.363* SARVI	0.519	0.470
Model 12	AGB = -144.688 - 137.12* SAVI + 170.671* SQRT	0.619	0.530
Model 13	AGB = 2515.075 + 1380.66* SAVI - 170.25* MSR -3422.3* TNDVI	0.660	0.650
Model 14	AGB = -16.132 + 399.983* NDVI - 178.568* SAVI + 6.611* SARVI	0.531	0.477
Model 15	AGB = -138.995 + 5.539* SAVI - 228.75* MSR -48.123* SARVI + 189.113* SQRT	0.673	0.609
Model 16	AGB = 770.014 - 3.423* SARVI + 111.875* SQRT + 361.99* SAVI - 1183.99* TNDVI	0.621	0.529
Model 17	AGB = 2815.92 + 1630.01* SAVI - 273.62* MSR -52.382* SARVI - 3820.1* TNDVI	0.690	0.638

TABLE II

REGRESSION MODELS FOR *EUCALYPTUS CAMALDULENSIS* (SUFEDA) BETWEEN FIELD MEASURED AGB AND SATELLITE DERIVED VEGETATION INDICES

Regression Model	Equations	R Square Value	R Square Validation
Model 1	AGB = - 89.284 + 958.880* NDVI	0.820	0.733
Model 2	AGB = - 89.286 + 639.262* SAVI	0.820	0.627
Model 3	AGB = - 72.146 + 921.929* MSR	0.493	0.276
Model 4	AGB = 33.483 + 407.435* SARVI	0.725	0.375
Model 5	AGB = - 1347.51 + 1732.41* TNDVI	0.820	0.631
Model 6	AGB = - 604.064 + 583.251* SQRT	0.807	0.611
Model 7	AGB = -1227.86 + 97.968* SQRT + 1447.041* TNDVI	0.820	0.628
Model 8	AGB = - 591.736 + 63.959* MSR + 559.273* SQRT	0.808	0.615
Model 9	AGB = - 87.766 + 468.674* MSR + 318.982* SARVI	0.818	0.637
Model 10	AGB = - 35.2057 + 1057.189* NDVI - 60.670* SQRT	0.820	0.629
Model 11	AGB = - 86.5292 + 929.888* NDVI + 13.998* SARVI	0.820	0.625
Model 12	AGB = - 35.200 + 704.809* SAVI - 60.678* SQRT	0.820	0.629
Model 13	AGB = - 868.28 -43.372* MSR + 259.287* SAVI + 1080.214* TNDVI	0.821	0.624
Model 14	AGB = - 91.100 -7434168* NDVI + 33.521* SARVI + 4956775* SAVI	0.824	0.605
Model 15	AGB = - 16.475 - 228.913* MSR -126.025* SARVI + 991.328* SAVI - 75.534* SQRT	0.821	0.619
Model 16	AGB = - 7742.48 + 38.026* SARVI -3895.89* SAVI + 947.386* SQRT + 9382.77* TNDVI	0.821	0.619
Model 17	AGB = - 814.918 -239.642* MSR + 545.906* SAVI + 1007.735* TNDVI - 128.332* SARVI	0.821	0.618

TABLE III

REGRESSION MODELS FOR *BOMBAX CIEBA* (SIMAL) BETWEEN FIELD MEASURED AGB AND SATELLITE DERIVED VEGETATION INDICES

Regression Model	Equations	R Square Value	R Square Validation
Model 1	AGB = - 223.779 + 1340.593* NDVI	0.740	0.842
Model 2	AGB = - 223.78 + 893.737* SAVI	0.740	0.842
Model 3	AGB = - 290.957 + 1520.07* MSR	0.691	0.642
Model 4	AGB = - 82.589 + 633.476* SARVI	0.614	0.852
Model 5	AGB = - 2023.58 + 2465.023* TNDVI	0.731	0.833
Model 6	AGB = - 874.604 + 769.268* SQRT	0.766	0.877
Model 7	AGB = - 640.552 + 914.090* SQRT- 483.174* TNDVI	0.767	0.882
Model 8	AGB = - 754.117 + 444.898* MSR + 578.074* SQRT	0.778	0.832
Model 9	AGB = - 272.14 + 301.504* SARVI + 1016.018* MSR	0.754	0.793
Model 10	AGB = - 1045.89 - 370.96* NDVI + 978.198* SQRT	0.767	0.884
Model 11	AGB = - 270.971 + 2043.98* NDVI - 381.28* SARVI	0.758	0.795
Model 12	AGB = - 1045.87 - 247.273* SAVI + 976.164* SQRT	0.767	0.884
Model 13	AGB = 8535.132 + 4930.208* SAVI - 12042.4* TNDVI + 584.934* MSR	0.778	0.824
Model 14	AGB = - 236.228-5.2E+07* NDVI - 248.371* SARVI + 34500496* SAVI	0.791	0.834
Model 15	AGB = - 1049.13 - 3538.9* MSR -2682.6* SARVI + 4902.74* SAVI + 944.856* SQRT	0.792	0.846
Model 16	AGB = - 28387.5 - 257.12* SARVI -15209.6* SAVI + 3408.71* SQRT + 34533.79* TNDVI	0.789	0.862
Model 17	AGB = 8401.317 - 3458.93* MSR -2669.84* SARVI + 10213.5* SAVI - 11838.8* TNDVI	0.787	0.833

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