ASSESSMENT OF RICE BIOMASS PRODUCTION AND YIELD USING SEMI-PHYSICAL APPROACH AND REMOTELY SENSED DATA

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ABSTRACT:

India is one of the world's largest producers of rice, accounting for 20% of all world rice production. Rice crop occupies nearly 27.6% of the India's arable land with average consumption per capita/year was ~68.2 kg milled rice. Being a staple food it is crucially important for policy makers, planners and researchers to have an accurate estimate before the harvest of crop. Timely and accurate statistics helps planners, and decision makers in formulating policies in regard to import/export in the event of shortfall and/or surplus. In the present study it is tried to evaluate the applicability of the remote sensing for yield estimation of major rice growing states of India. Recent advances on the resolutions (i.e., spectral, spatial, radiometric, and temporal) and availability of remote sensing imagery allowed us timely collection of information. This study developed an intermediate method called semi-physical method using remote sensing and the physiological concepts such as the Photo-synthetically Active Radiation and the fraction of PAR absorbed by the crop. Net Primary Product was computed using the Monteith model. Rice yield was computed using the actual NPP, Radiation use efficiency and Harvest index. The study was carried in *kharif* season 2018-19. Although model gives slight difference of yield with respect to actual and the estimated yield and DES yields within the range of ± 10%, which confirms the utility of model and can be used for the operational estimates of rice crop.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is the most consumed cereal grain food in the world constituting the dietary staple food of more 60% of the world population. It is estimated that more than 50 kg of rice being consumed per capita per year worldwide (FAO, 2016), while India's average consumption per capita/year was ~68.2 kg rice. In India, rice is cultivated on an area of over 43.81 million ha, which is 27.6% of the total cultivated area, with an annual production of 108.5 million metric tons rice and productivity of 2.86 metric tons per hectare (Anonymous, 2017-18). India occupies the 2nd position in terms of rice production worldwide after China. So for primarily agriculture based country like India, the spatial distribution of rice fields, monitoring crop development and growth, and the early prediction of crop yield are of great importance for planners and policy makers and for the management of food security and water resources. Timely and accurate statistics helps planners, and decision makers in formulating policies in regard to import/export in the event of shortfall and/or surplus.

India is one of the few countries which have a well-established system of collection of agriculture statistics since 1884. The agricultural crop production of principal agricultural crops in the country is usually estimated as a product of area under the crop and the average yield per unit area of the crop. Crop acreage assessment at a district level are obtained through complete enumeration whereas the average yield is obtained through general crop estimation surveys (GCES) based on crop cutting experiments conducted on a number of randomly selected fields in a sample of villages in the district. The crop forecasts/advanced estimates of crops are presently developed by the Ministry of Agriculture. However, these reports are often subjective, expensive, laborious, time-consuming, and prone to errors, which may result in poor crop area and yield estimations. Also, in most state, data on crop area and yield arrive late to analyse, make inferences, and take appropriate measures for avoiding food shortages. With the advent of remote sensing Technology during 1970s, these tools are used worldwide for identification and monitoring of agricultural crops and for forecasting of crop yields and acreage under cultivation. Numerous approaches to early estimate of the yield of crops on the basis of remote sensing data (RSD) have presently been developed. Mainly used for this purpose are the data of moderate (MODIS) and low (NOAA, VHRR, MSG, SPOT VEGETATION) spatial resolution, which allow obtaining current information on the state of crops with high economic efficiency (Royer & Genovese, 2004).

The most common approaches are based on regression model developed on the direct empirical relationship between indicators obtained from satellite data such as normalized difference vegetation index (NDVI) measurements and leaf area index (LAI), crop yield and statistical data (Son, Chen, Chen, Minh, & Trung, 2014); (Bala & Islam, 2009); (Dabrowska-Zielinska, Kogan, Ciolkosz, Gruszczynska, & Kowalik, 2002); (Mkhabela, Bullock, Raj, Wang, & Yang, 2011). The important assumption in use of remote sensing data for crop modelling is that the spectral data is strongly related with canopy parameters which are related to final yield. Several studies have established good correlation between vegetation indices and grain yield like Colwell et al. 1997, Serafini 1985, Barnett and Thompson 1982, 83. Looking at the pros and cons of the empirical based models, it is wise to think of an intermediate crop yield forecast method based on the use of remote sensing and the physiological concepts such as the photosynthetically active solar radiation (PAR) and the fraction of PAR absorbed by the crop (fAPAR)

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in Monteith's efficiency equation (Monteith, 1977). PAR (400 - 700 nm) is a fraction of incoming solar radiation. A value of approximately 45–50% is generally accepted to represent the 24 h average PAR (Moran, Maas, & Pinter, 1995), as the PAR fraction varies with visibility, optical depth and ozone amount (Frouin & Pinker, 1995). A fraction of PAR absorbed by the canopy (APAR) will be used for carbon dioxide assimilation. The Net Primary Productivity (NPP) is estimated by applying linear relation of NPP to the photo-synthetically active radiation (PAR) absorbed by vegetation (APAR) and the plant radiation use efficiency (RUE) which is the energy conversion coefficient of absorbed radiation into above ground biomass. These measurements were used to derive intercepted yield which is the summation of intercepted radiation conversion during whole growth period of rice crop and constant harvest index.

Tripathy et al. (2014) have used this approach for wheat district/state level wheat yield estimation, while Chaurasiya et al. (2017) used the approach for sugarcane yield estimation.

This method, however, gives a potential crop yield rather than an actual yield. As radiation conversion efficiency is affected by nitrogen deficiency (Sinclair & Horie, 1989) and water stress, while harvest index is influenced by water or temperature stress during reproductive and grain-filling stages. The present study carried out with the objective to estimate the yield of rice crop using Monteith equation at state level using remotely sensed biophysical parameters.

2. STUDY AREA

Study Area comprises 337 districts of thirteen major *kharif* rice growing states (Punjab, Haryana, Madhya Pradesh, Uttar Pradesh, Bihar, Andhra Pradesh, Chhattisgarh, Jharkhand, Karnataka, Telangana, Assam, Odisha and West Bengal) during the year 2018-19 (Figure 1). These 13 states cover 85.7% of total *kharif* rice area and 85.8% of the total *kharif* rice production of the country (FASAL *kharif* rice report, MNCFC 2018-19). Among these states Uttar Pradesh and West Bengal constitute the major growing area and production while Punjab, Haryana, Andhra Pradesh and Telangana constitute highest yield.

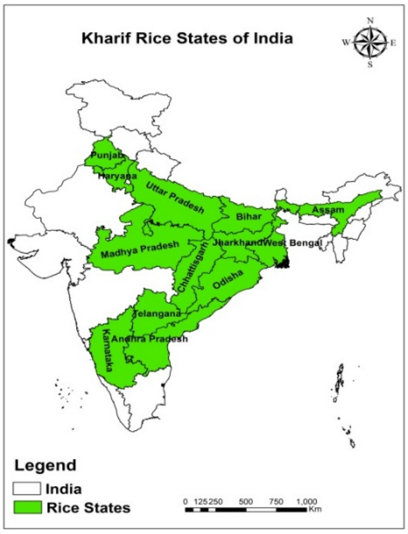

Figure 1: Study Area

3. DATA USED

The Insolation INSAT-3D imager (http://www.mosdac.gov.in) daily data of 1Km resolution was used to estimate PAR value. MODIS Terra 8-day FAPAR and spectral reflectance data product of 72 days (http://LPDAAC.usgs.gov) from the (04 July 2018 to 29 September 2018) was used in the analysis. The data were processed though ERDAS Imagine and ENVI; image processing software to derive the LSWI which was calculated from the NIR and SWIR band and NDVI which was calculated using NIR and RED band. The LSWI was in particular, used to identify the initial period of flooding and transplantation of the rice; while NDVI was used for understanding the greenness of the crop. Sentinel-1A SAR data has been used for kharif rice crop layer (FASAL Project, MNCFC). IMD ground station based daily maximum and minimum temperature data was used for estimation of temperature stress over crop area, while RUE were taken from literature and old reviews, whereas Harvest Index for the *kharif* rice were calculated using state wise CCE data.

SN	Data / Product	Satellite /ground	Sensor	Resolution	Source
1.	Daily integrated Insolation	INSAT-3D	Imager	1 Km	www.mosdac.gov.in
2.	8-days composite FAPAR	Terra	MODIS	0.5 km	LPDAAC@usgs.gov
3.	8-days composite surface reflectance	Terra	MODIS	0.5 km	LPDAAC@usgs.gov
4.	Crop (*Kharif* Rice) mask	Sentinel	Sentinel -1A	20 m	MNCFC
5.	Daily Tmin and Tmax	Ground Station of IMD		0.5° x 0.5°	IMD, Pune data
6.	RUE max				Old Literature
7.	Harvest Index				CCE based

Table 1: Details of satellite data products used in this study are as follows:

4. METHODOLOGY

The yield forecasting methodology is based on monitoring the daily increase of plant biomass from the start of the growing stage to maturity stage. The essence of the given approach is that plant growth is potentially predetermined by incoming solar radiation i.e. the amount of photosynthetically active radiation (PAR) absorbed and the crop's PAR interception capacity. For this the equation developed by Monteith (1977) to quantify the fAPAR. fAPAR is defined as the fraction of absorbed PAR (APAR) to incident PAR (0 < fAPAR < 1). Where, PAR is cumulative intercepted photo synthetically active radiation. The photo synthetic active radiation can be calculated by using the following formula

$$\mathbf{PAR = Rs * 0.5} \quad (1)$$

The model of accumulation of rice biomass can be written in a general form in the following way:

$$\textbf{NPP = fAPAR * PAR * RUE} \qquad (2)$$

Where, NPP = Net Primary Productivity/ dry matter accumulation in plant over a period of time ($gm^{-2}d^{-1}$); PAR = photosynthetically active radiation ($MJm^{-2}d^{-1}$); fAPAR= fraction of incident PAR which is intercepted and absorbed by the canopy (dimensionless); RUE = Radiation-use efficiency of absorbed photosynthetically active radiation (gMJ^{-1}).

Radiation use efficiency (RUE) is described in as:

$$\textbf{RUE } (gMJ^{-1}) = \textbf{Biomass } (g/m2) \,/\, \textbf{PAR } (M\,J/m^2/day) \qquad (3)$$

Where, Rs = incoming solar radiation (MJm^{-2})
The impact of water stress (Wstress) and temperature stress (Tstress) on photosynthesis has also observed and hence the modified equation becomes:

$$\textbf{NPP = fAPAR * PAR * RUE * W}\,\textit{stress}\,\textbf{* T}\,\textit{stress} \qquad (4)$$

The economic grain yield is the product of harvest index (HI) and net primary productivity (NPP). That is:

$$\textbf{Grain Yield} = \sum_{Sowing}^{Harvesting} NPP * HI \qquad (5)$$

Where Harvest Index (H.I) is calculated from ancillary CCE data using the formula:

$$\textbf{H.I = Grain Yield (Kg/ha)/ Biomass Yield (Kg/ha)} \qquad (6)$$

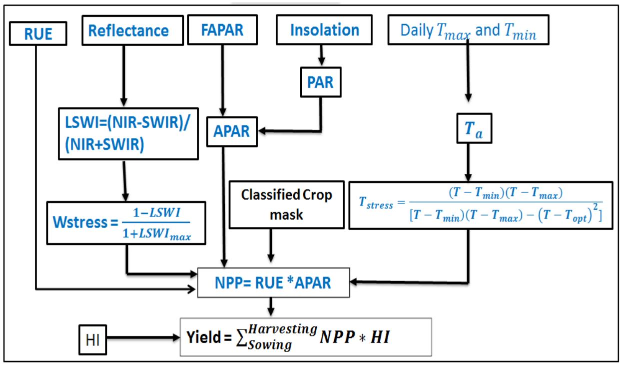

Figure 2: Flow Chart of Methodology for Rice yield estimation using RS

5. DATA PROCESSING AND COMPUTATION OF PARAMETERS

Multi-temporal datasets, MODIS, MOSDAC (INDSAT 3D), SAR (Sentinel 1A) were used for analysis. The maximum and minimum temperatures from Automatic Weather Station of IMD were used in the study. ERDAS IMAGINE; ENVI +IDL and ARCGIS software were used for digital data processing, analysis and integration of spatial and non-spatial data. The MODIS data was geo-referenced and converted the projection to Geo Lat/Long (WGS 1984). Rice crop mask was used that had been generated from Sentinel 1A SAR data with 20 m resolutions under FASAL Project.

5.1 Image acquisition and processing of INSAT 3D Imager insolation product:

Insolation data product of INSAT 3D imager was downloaded from MOSDAC data source link (www.mosdac.gov.in) on daily basis over the crop season i.e., from 04 July 2018 to 29 September 2018, with 1 km spatial resolution. The processing of daily insolation involved the conversion of daily insolation using ENVI+IDL software to 8 day product (Sum) and resampling to 500 m resolution. 50 % of the total insolation was assumed as photo-synthetically active radiation (PAR).

5.2 Image acquisition and processing of MODIS data product:

MODIS surface reflectance products (8 day composites) with 0.5km spatial resolution; fAPAR product (8day composites) with 0.5km resolution has been downloaded from (https://lpdaac.usgs.gov). These products are in HDF format with the sinusoidal projection.

MOD09A1 or MODIS Surface Reflectance 8-Day L3 Global file is a composite using eight consecutive days with 500 m resolution of nine tiles to cover whole India. The composite contains seven spectral bands of data in the visible and infrared region with a band width i.e. Band 1: 0.620-0.670 µm; Band 2: 0.841-0.876 µm; Band 3: 0.459-0.479 µm; Band 4: 0.545-0.565 µm; Band 5: 1.230-1.250 µm; Band 6: 1.628-1.652 µm and Band 7: 2.105-2.155 µm.

The MOD15A2H data product contains crop factor data e.g. Leaf Area Index (LAI) and (fAPAR) 8-day (Global, 500m spatial resolution) from Terra satellite in the sinusoidal projection. MOD09A1 and MOD15A2H data products were acquired over the *kharif* rice crop season duration from 04 July 2018 to 29 Sept. 2018, and processed. The processing of MODIS data included the mosaicking of nine tiles for India, resizing to India boundary, conversion to geographical projection from the sinusoidal projection, cloud pixel elimination.

5.3 Computation of Water stress:

It was reported that the SWIR band (1.6 µm) was sensitive to plant water content (Tucker, 1980). Hence Land Surface Water Index (LSWI) is derived as the normalized difference between the NIR (0.78–0.89 Am) and SWIR (1.58–1.75 µm) spectral bands for water stress assessment. This index is sensitive for the total amount of vegetation and soil moisture. The equation to calculate LSWI is given as:

$$\textbf{LSWI} = \frac{(\rho_{NIR} - \rho_{SWIR})}{(\rho_{NIR} + \rho_{SWIR})} \qquad (7)$$

Estimated LSWI was further used in calculating water stress scalar (Wstress) (Xiao, et al., 2004).

$$W_{Stress} = \frac{1-LSWI}{1-LSWI_{max}} \qquad (8)$$

Where, LSWI is value of particular pixel and LSWImax is spatial maximum of the state on a particular day.

5.4 Computation of temperature stress:

Daily average temperature has been computed from the daily maximum and minimum temperature of IMD weather data interpolated to 0.5° grid. The daily temperature stress in a scale of 0-1 has been computed using eq9. The average temperature stress over an 8 days period was computed and all images were converted to 0.5 X 0.5 km resolution. The Temperature stress is calculated using the equation (Raich, et al., 1991).

$$T_{stress} = \frac{(T-T_{min})\,(T-T_{max})}{\left[(T-T_{min})(T-T_{max})-(T-T_{opt})^2\right]} \qquad (9)$$

Where T_{min}= minimum temperature for photosynthesis (°C); T_{max}= maximum temperature for photosynthesis (°C); T_{opt}= optimal temperature for photosynthesis (°C); T= the daily mean temperature (°C).
For Rice, T_{min} = 14°C; T_{max} = 40°C and T_{opt} = 30°C and if air temperature falls below T_{min}, T_{stress} is set to be zero.

5.5 Computation of Net Primary Product and grain yield:

NPP has been computed for a period of sowing to harvest date at an interval of 8 days for each state with a spatial resolution of 500m using the periodical PAR, fAPAR, Wstress, Tstress and maximum radiation use efficiency in eq3. Total NPP has been computed for each state using the crop duration. From the total NPP grain yield per pixel has been computed using eq5. The pixel yield was averaged to district level and average state level yield computed.

5.6 Validation: The yield estimates from this model were evaluated by comparing the estimated *kharif* rice yield with the district wise Directorate of Economic and Statistics (DES) data (average of three years).

6. RESULT AND DISCUSSION

Rice yield was computed for period of sowing to harvest at an interval of 8 days from July 4, 2018 to September 29, 2018 which was considered as *kharif* rice crop season on basis of ground truth data and NDVI profile of *kharif* rice. The ground truth is collected by the state agriculture department officials using a smartphone based Android App, called Bhuvan FASAL, developed by NRSC (ISRO). The ground truth for rice crop was collected during August-September, 2018. The ground truth data included location, file photographs and field parameters, which are uploaded to Bhuvan Portal.

Rice GT points were plotted transplantation date wise (Figure 3). From the plots of it can interpreted that sowing is done in the month of June & July for the states (Punjab, Haryana & Madhya Pradesh): July, August & September for the states (Andhra Pradesh, Bihar, Chhattisgarh, Jharkhand, Telangana, Uttar Pradesh & West Bengal) and August & September for states (Karnataka & Odisha).

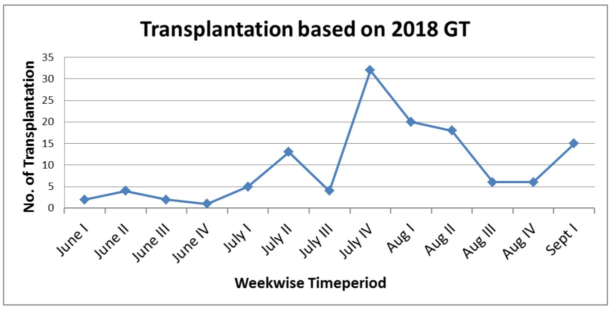

Figure 3: Transplantation plot for Andhra Pradesh based on GT points

NDVI profile of paddy crop in various states also represented same pattern of transplanting of crop (Figure 4). It interpreted that crop greenness increases nearly at Julian date 193 i.e. 12 July, 2018 which means that sowing is done in month of July for the states Punjab, Haryana, Madhya Pradesh, Bihar, Chhattisgarh & Uttar Pradesh.

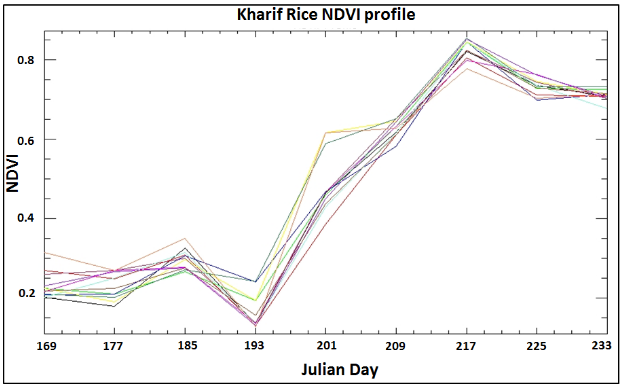

Figure 4: *Kharif* Rice NDVI Profiles for Uttar Pradesh

The water stress was applied up to panicle initiation stage of the crop growth. Among the thirteen paddy states, maximum water stress was observed in Andhra Pradesh in the month of mid-July to end of crop season. While in other study states water stress varied from 0.76 to 1 in scale of 0-1, in which value 0 represent maximum stress and value 1 represent no stress. Image of LSWI and the corresponding water stress map for an 8 day period (from 13-20 August, 2018) has been depicted in Figure 5. The same trend was observed for other dates also.

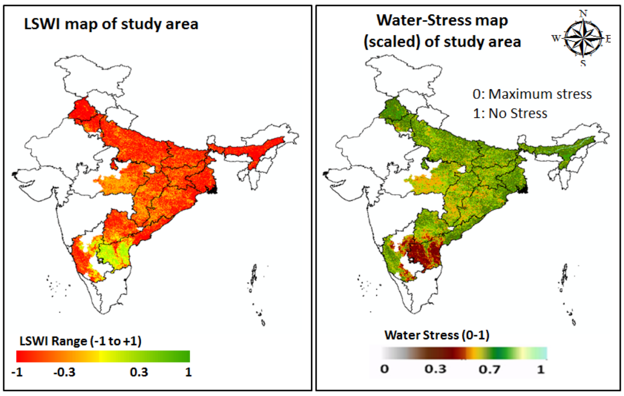

Figure 5: LSWI & Water Stress map of study area during 13-20 Aug, 2018 (1: No stress; 0: Maximum stress)

Average temperature stress over a period of 8 days in a scale of 0-1 was derived from the average interpolated temperature depicted in Figure 6. For the whole crop period the temperature stress was calculated over the study area using the daily gridded maximum and minimum temperature of IMD weather data.

Net Primary Product has been computed state wise over the growing period at an interval of 8 days using the state-wise maximum radiation use efficiency of the major cultivar in the respective state. NPP has been calculated using equation 4. Hence for the whole crop duration (4 July-29 Sept, 2018) periodically absorbed Photo-synthetically Active Radiation (APAR) was observed by computing 8 day composite photo-synthetically active radiation (PAR) and fAPAR. PAR & fAPAR of whole India for 8 days period (13-20 August) has been depicted below (Figure 7). This 8 day periodic data of APAR is integrated for whole crop season for the study area using *kharif* rice crop mask (Figure 8).

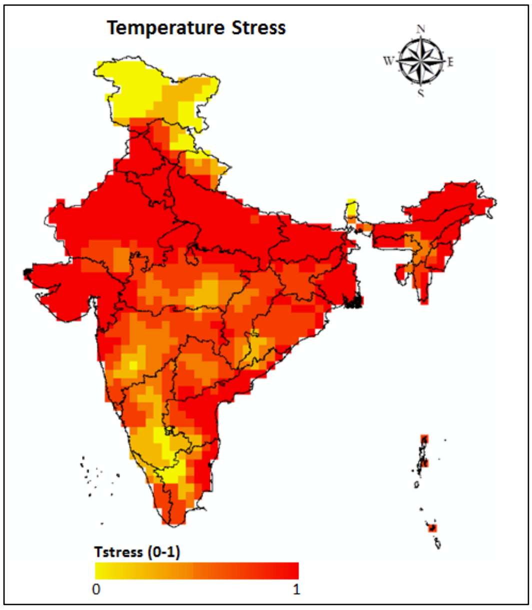

Figure 6: Temperature Stress map of India during 13-20 Aug, 2018 (1: No stress; 0: Maximum stress)

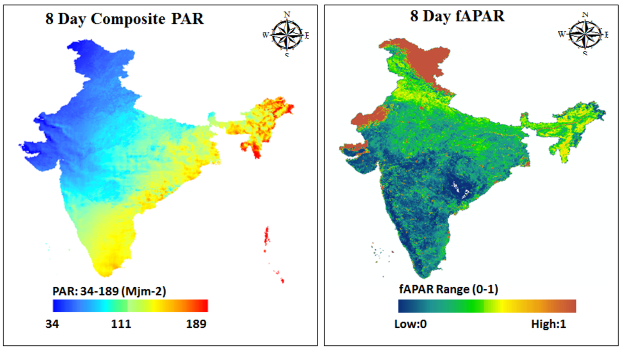

Figure 7: 8 Day Composite PAR & fAPAR map of India during 13-20Aug, 2018

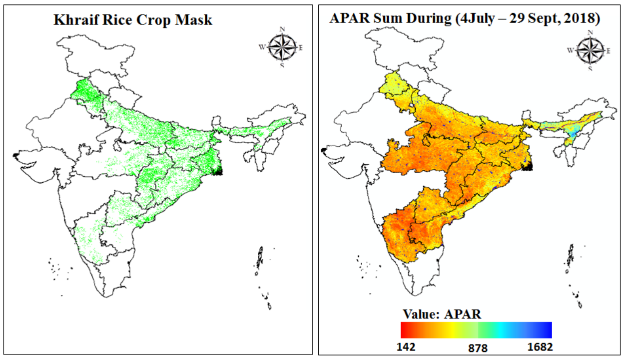

Figure 8: *Kharif* Rice Crop Mask & Sum of APAR (4 July - 29 Sept, 2018)

Grain yield was computed from total NPP using the harvest index of the respective cultivar in each state. The state wise harvest index ranged from 1.8 to 2.85. The distributed yield map is shown in Figure 9. It shows the regions of high yield and low yield. The state wise estimated grain yield ranged from 1.694 t/ha in Chhattisgarh to 3.989 t/ha in Punjab.

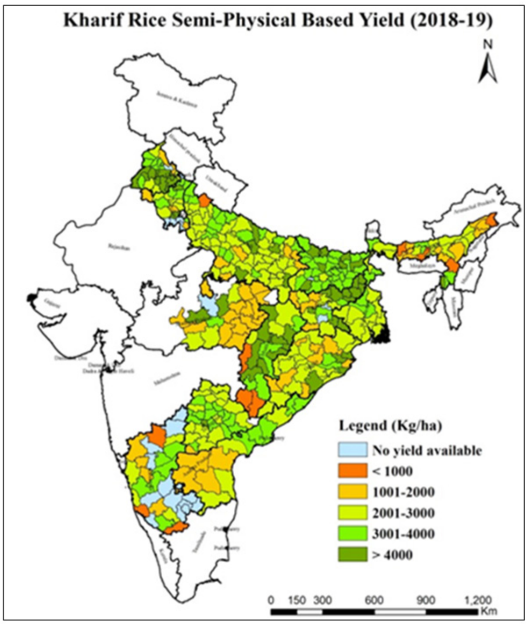

Figure 9: *Kharif* Rice Yield Map of Year 2018-19

The state level comparison with the reported DES yield indicated an average underestimation of 3.94 %. In each state the estimation remained the range of ± 10% with compare to reported DES yield of last three year 2015-18 (Table 2 and Figure 10). The absolute difference between reported and semi-physical grain yield was found to be least in AP (1.11 %) and highest in Jharkhand (9.65 %). The RMSE between reported DES and calculated Semi-physical method grain yield in different states was found to be 0.15 t/ha and R^2 of the thirteen *kharif* rice growing states resulted in a R^2 of 0.97 (Figure 10).

State	Semi-Physical yield (t/ha)	DES yield (t/ha) (2015-2018)	Diff (%)
Andhra Pradesh	3.158	3.193	-1.11
Assam	2.114	1.938	8.33
Bihar	2.425	2.219	8.49
Chhattisgarh	1.694	1.814	-7.08
Haryana	3.175	3.118	1.80
Jharkhand	2.403	2.171	9.65
Karnataka	2.797	2.617	6.44
Madhya Pradesh	1.922	1.841	4.21
Odisha	1.957	1.785	8.79
Punjab	3.989	4.057	-1.70
Telangana	3.059	2.943	3.79
UttarPradesh	2.443	2.239	8.35
West Bengal	2.773	2.738	1.26
Average	**2.608**	**2.513**	**3.94**

Table 2: Comparison of estimated yield with reported DES yield

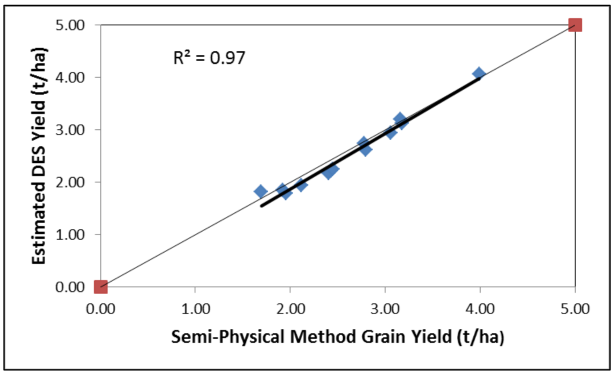

Figure 10: Comparison of DES yield with RS based yield

7. CONCLUSION

The present study is based on Monteith (1977) approach for spectral yield modelling to estimate the Net Primary Productivity of *kharif* rice crop in major growing states of India. The outcome of this study demonstrated that the yield of crop is depending upon the absorbed photo synthetically active radiation. The product of radiation uses efficiency (RUE) and harvest index (H.I) also an important parameter to estimate the net productivity of the crop. The results from this study demonstrated that this model can be used to predict paddy yield at state level. This study will be able to provide the spatial *kharif* rice yield map, as well as the state level aggregated *kharif* rice yield forecast.

Possible reason for disparity in spatial yield with DES estimation may be attributed to the error in sowing dates and harvesting dates. This spectral yield model provides rice yield with about 0.15 t ha-1 RMSE at state level. This model needs further improvement through spatial planting date from remote sensing and the judicious use of harvest index and radiation use efficiency values, to estimates the yield at district level and also district-wise harvest index values derived from field data.

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