RICE GRAIN YIELD ESTIMATION OVER SOME ASIAN COUNTRIES USING ISRO’S SCATSAT-1 KU-BAND SCATTEROMETER DATA

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ABSTRACT:

Rice crop monitoring and yield prediction at country-scale can be effectively done using high-repeat active microwave remote sensors due to its all-weather observation capability of land surface. The Ku-band with a frequency of 13.515 GHz has the ability to interact with the surface layer and hence is useful for providing information on top portion of canopy and hence the grain and awns of rice crop. Also it has the capability to generate information over the whole region of South Asia in one day. Hence the present study was carried out to explore the super resolved Ku band back scattering coefficient from space borne scatterometer (SCATSAT-1) for rice productivity assessment over six Asian countries (India, Pakistan, Nepal, Bangladesh, Myanmar and Sri Lanka). The super resolved sigma-0 in both polarization (H and V) for the kharif rice season of 2017 (May to Mid-Nov) was used for this study. The temporal backscatter was used to generate rice planting date using polynomial fitting. Multiple regression models were developed using the daily SH/SV ratio and the farm-level fresh paddy yield collected through the Crop Cutting Experiment (CCE). The validation of the model was done for India at state level. For other countries national average reported yield was compared with the estimated yield. The rice planting date was found to vary from first week of June to last week of August in different parts of the six countries. Country average yield was found to vary from 3.45 t ha-1 in Sri Lanka to 4.32 t ha-1 in Myanmar. The absolute difference was lowest in India (8 %) followed by Sri Lanka (-11 %) and maximum in Nepal (35 %). In Indian states, the validation results showed a correlation coefficient of 0.95 at state level with a RMSE of 0.28 tha-1 (11.4% of mean reported yield). This study showed the possibility of using high frequency and high resolution Ku-band back scattering coefficient for rice grain yield estimation at continental scale such as Asia. The yield estimation can be further improved with the use of country-wise crop cutting data for model development and validation.

1. INTRODUCTION

South Asia comprising of Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka accounts for almost 40% of the world’s harvested rice area and almost 25% of the world’s population (Gumma et al. 2011). The population of the region is projected to grow faster than its ability to produce sufficient rice to meet the demand making South Asia food insecure in coming decades (Papademetriou, 2000). Thus, rice-based agricultural systems are a vital component of any strategy to ensure food security in this region. Monitoring rice growth and predicting rice yield over a large region like South Asia before harvest will provide valuable information to planners, decision makers, and scientists to find out zones of low and high yield in that region so that export import decision can be made. Also proper management may be planned specifically for the regions of low yield if it can be known prior to harvest.

Majority of the rice crop is cultivated in kharif season when there is adequate rainfall and typically with cloud cover in the whole season. Microwave energy from an active sensor is able to penetrate cloud and rainfall to some extent depending upon their frequency and wavelength. India has the operational programme of National Rice Crop Monitoring that used multi-date RISAT - 1 (C-band, 5.3 GHz and HH, HV polarisation) data as well as sentinel-1 with C–band SAR to estimate rice area; and uses optical remote sensing and weather based model for providing rice yield operationally at Mahalanobis National Crop Forecasting Centre (MNCFC). New researches are now oriented towards exploring the feasibility of estimating rice crop yield from microwave backscatter data from scatterometer due to their high temporal resolution and more spatial coverage. The Ku-band with a frequency of 13.515 GHz has the ability to interact with the surface layer and hence is useful for providing information on top portion of canopy and hence the grain and awns of rice crop. Ku band scatterometer data has been used by many researchers for exploring it’s capability in crop research especially for cereal grain crops (Ringelmann et al. 2004; Oza and Parihar, 2007; Inoue et al., 2002). These researches used data from space based and ground based platforms and showed the utility of the Ku-band backscatter for estimating planting date of wheat and rice as well as for fresh grain yield of rice.

Ku-band scatterometer from SCATSAT-1 provides global coverage within 2 days, thus has the advantage to generate this information more frequently. The availability of high spatial or super resolution (2km) back scattering data of the Ku-band in VV and HH polarization from SCATSAT-1 platform made this data more useful as compared to the data at its original resolution (25 km). SCATSAT-1 satellite carrying Ku band Scatterometer was launched on 26th September, 2016. It provides backscattering coefficient (sigma-naught) over whole globe and wind vector over ocean surface. The instrument is a pencil beam wind Scatterometer operating at Ku-band of 13.515 GHz. The two pencil beams, inner and outer, result in a constant angle of incidence for both beams; this allows σ0 measurements at multiple (4 or 2) azimuth angles for the same point on the ocean surface.

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Variations of the radar scatterometer signal are mainly caused by changes of the dielectric properties of the scattering surface and by changes of the scattering mechanism as introduced by changes of surface roughness and contributions by mainly surface scattering. For vegetation, the main reasons of these variations are changes in moisture and the change in top canopy structure due to growth of vegetation. Microwave energy in short wavelength SAR as in Ku and X band interact mainly with the top portion of the canopy layers, thus are useful to estimate important plant parameters such as fresh grain weight and grain yield (Moran et al., 1998; Brisco and Brown, 1998). Also it has the capability to generate information over the whole region of South Asia in one day.

Looking at the need for the rice yield prediction over South Asia and the potential of back scatter data from Ku band scatterometer of SCATSAT-1 satellite for the same the present study was carried out to explore the super resolved Ku band back scattering coefficient from space borne scatterometer on-board SCATSAT-1 for rice productivity assessment in the six important South Asian countries.

2. STUDY AREA

The study area comprises of six major rice growing South Asian countries, viz., India, Pakistan, Nepal, Bangladesh, Myanmar and Sri Lanka (Fig. 1). The capability of the scatterometer to scan the whole region daily inspired us to take this broad study area. The study area differs in terms of climate, soil and rice ecosystems. Climate of the study area varies from subtropical in Bangladesh and East India to semiarid temperate in N-India and Nepal. Soil varies from loamy sand to clayey. Rice ecosystem includes lowland rainfed system, irrigated system, deep water system as well as upland systems. The seasonal pattern of precipitation is driven by the monsoon climatic system in the region. It brings rain during May to September.

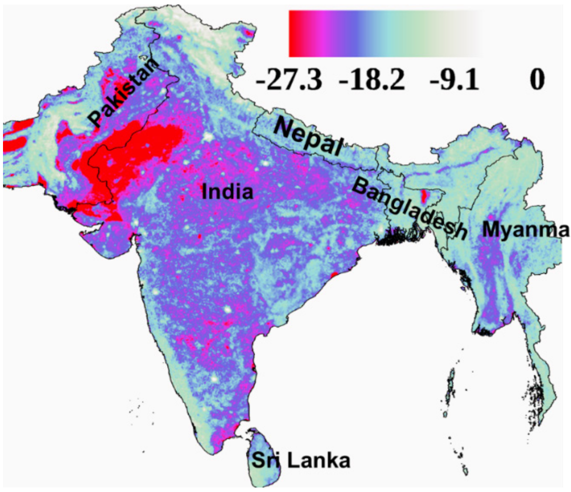

Figure 1. Sigma-0 from Ku band scatterometer of SCATSAT-1 in HH Polarization over the study area with the country boundary

3. DATA

The study used both satellite and field based experimental data (Table 1). SCATSAT-1 satellite carrying Ku band Scatterometer provides backscattering coefficient (sigma-naught) over whole globe and wind vector over ocean surface at 25 km original resolution. The instrument is a pencil beam wind Scatterometer operating at Ku-band of 13.515 GHz. SCATSAT-1 Data Products System is operational at NRSC, Shadnagar. L1B products are scan-mode products (~6x30km spatial resolution). L2A and L2B are swath-gridded products (50X50 and 25x25km) while L3 products are generated on a global grid. Super resolution backscattering coefficient (L4_India) is being generated at Space Applications Centre at 2kmx2km resolution using the Scatterometer Image Reconstruction (SIR) resolution enhancement algorithm (Long and Daum, 1997). For details of the procedure, readers may refer (Modi and Padia, 2015, Modi, 2016). This super resolved sigma-0 in both polarization (H and V) for the kharif rice season of 2017 (May to Mid-Nov) was used for this study.

Input (Baseline data)	Source
Daily SCATSAT- L4 data product of Sigma-0 in horizontal (SH) and vertical (SV) polarization over kharif rice season	MOSDAC (www.mosdac.gov.in)
Kharif rice crop mask	MNCFC (India) and IRRI published data (Nelson et al., 2015) (other countries)
Crop Cutting Experiment data over India	MNCFC
Reported yield (past five years reported yield by DES for India) data	www.dacnet.in, FAOSTAT, 2018
Village, Block, District and state boundaries	In-house SAC

Table 1: Data used for the analysis of rice growth phase and for developing rice grain yield model

4. METHODOLOGY

The temporal backscatter was used to generate rice planting date using polynomial fitting. Multiple regression models were developed for each of the 12 rice growing states in India representing different agro-climatic zones and water management practices using the daily SH/SV ratio and the farm-level fresh paddy yield collected through the Crop Cutting Experiment (CCE). In total 1042 CCE yield were collected form the 10 states of India and used for developing the pooled model (Table 2).

State	No of CCE point	Source
Bihar	588	CYMMIT
Chhattisgarh	47	MNCFC
Haryana	31	MNCFC
Jharkhand	4	MNCFC
Karnataka	47	MNCFC
Odisha	103	MNCFC
Punjab	51	MNCFC
Telengana	36	MNCFC
Uttar Pradesh (UP)	49	MNCFC
West Bengal (WB)	86	MNCFC
Total	1042	

Table 2. State wise no of CCE data

State-wise models also were developed for the 10 Indian states using the respective CCE yield and corresponding SH/SV ratio. The models for West Bengal and Bihar states were applied to estimate fresh rice grain yield of Bangladesh and Nepal, respectively while the pooled rice grain yield model was applied for other three countries. The model for India was used to estimate rice yield of other countries due to lack of CCE data in other countries. Rice mask for all countries except for India was taken from published data of IRRI, Phillipines (Nelson et al., 2015). For India rice mask was taken from MNCFC, New Delhi.

The validation of the model was done for India at state and district level. For other countries national average reported yield was compared with the estimated yield. Overall methodology is given in fig 2.

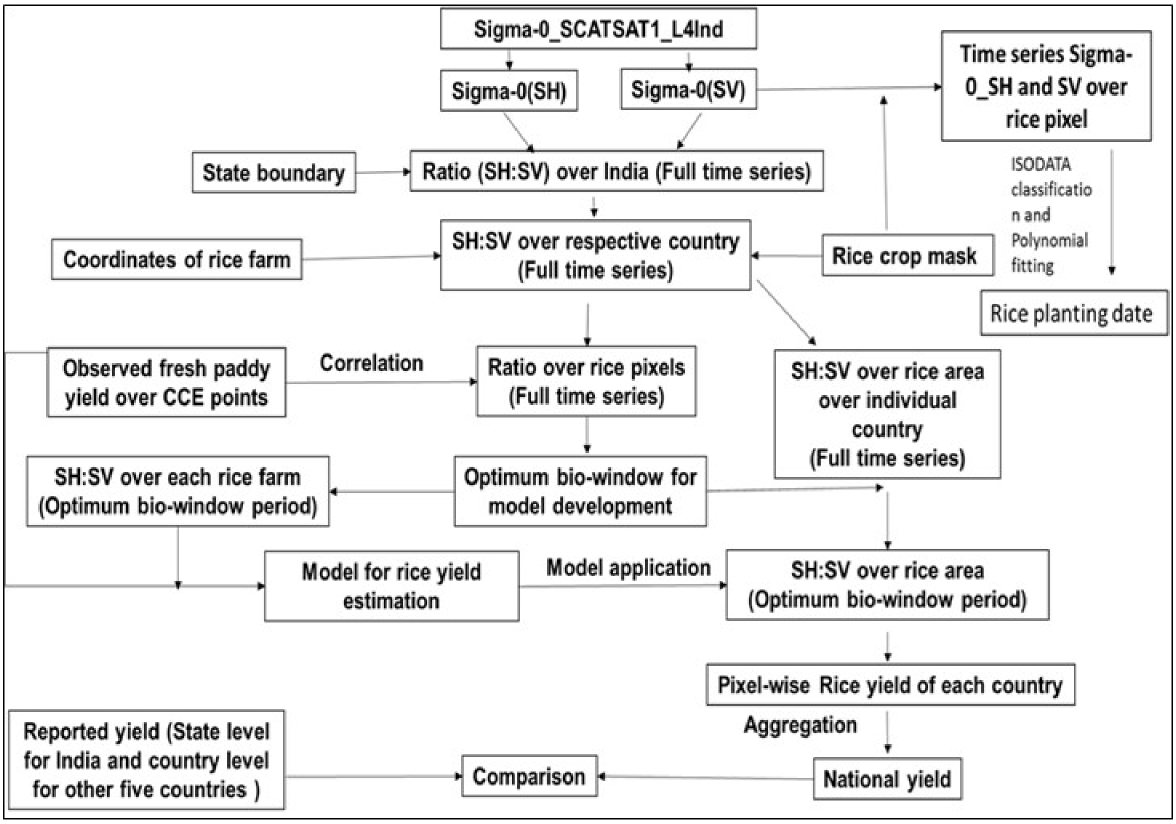

Figure 2. Approach and methodology for rice yield prediction with SCATSAT-1 data

5. RESULTS AND DISCUSSION

5.1 Temporal behaviour of Ku band backscatter at state level

The time series plots of sigma-0 in VV polarization in Punjab and West Bengal with contrasting water management is shown in fig 3. The time series sigma-0 showed a dual peak (one at maximum tillering stage and other at grain filling stage) and dual minima (one just prior to transplanting and one at the maximum LAI stage) in both the states. This may be due to the change in roughness of the rice morphology such as increase in roughness after the first minima coincides with the flooding stage (transplanting stage) due to increase in tiller number till the maximum tillering stage where the curve reaches the first maxima, followed by increase in smoothness due to leaf coverage resulted in the second minima at peak LAI. Thereafter, there is an increase in roughness due to development of panicles till the grain filling stage thus causing the second maxima followed by reduction in roughness due to covering of canopy with the rice grains till harvest.

The plots showed that peaks and minima’s are more prominent in Punjab as compared to those in West Bengal. In Punjab, rice crop is grown in irrigated condition in which soil becomes wet first rather than the top canopy. Hence, in Punjab, the roughness of crop canopy is only due to the rice structure and hence gives rise to a sharp peak; while reverse is in the case of West Bengal where the majority of rice area is rain-fed and rainwater affects the moisture content of the top canopy, reduces the roughness and the interactive signature results in number of peaks and drops as per the rainfall event. It may also be due to the fact that in Punjab rice is grown only in kharif season while in West Bengal both rabi and kharif season rice crops were contributing to the mixed signature of mature (rabi) and new (kharif) crops (fig 3).

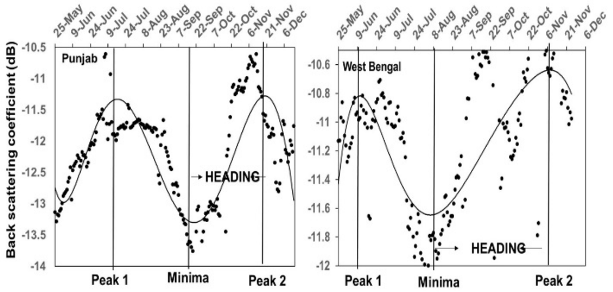

Figure 3. Temporal profile of sigma-0 (SV) over rice areas in Punjab and West Bengal

5.2 Rice planting date

The rice planting date was found to vary from first week of June to first week of August in different states of India. In Bangladesh the planting date varied from 11 July to 25 August in different parts during the Aman season. In Sri Lanka planting date varied from 29 June to 10 August; in Pakistan from 14 June to 26 June; in Myanmar from 11 June to 27 July and in Nepal it varied from 26 June to 27 July during 2017 (Fig 4).

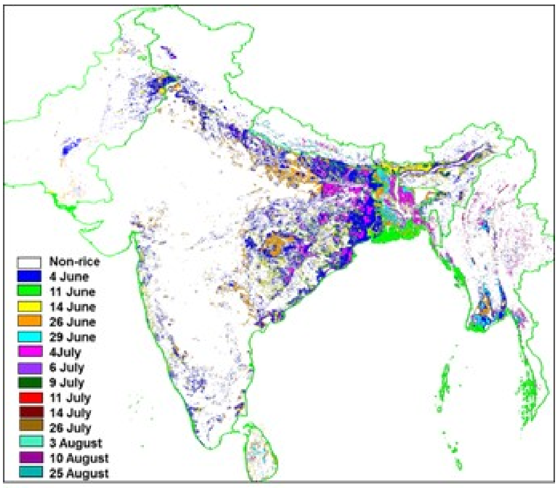

Figure 4. Planting date of rice in six South Asian countries

5.3 Yield model development

The details of the structure and coefficient of the state model are given in this section.

5.3.1 Structure of the Model for different state and the pooled model:

For UP and WB

$$Ypaddy = a*X1 + b*X2 + c*X3+d*X4+e*X5+C \qquad (1)$$

For Telangana, Haryana, Odisha

$$Ypaddy = a*X1 + b*X2 + c*X3+d*X4 +e*X5+f*X6+C \qquad (2)$$

For Chhattisgarh,

$$Ypaddy = a*X1 + b*X2 + c*X3+d*X4 +e*X5+f*X6+g*X7+C \qquad (3)$$

For Bihar and Karnataka,

$$Ypaddy = a*X1 + b*X2 + c*X3+d*X4 +e*X5 +f*X6 +g*X7 +h*X8 +i*X9+C \qquad (4)$$

For Punjab,

$$Ypaddy = a*X1 + b*X2 + c*X3+d*X4 +e*X5+f*X6+g*X7+ h*X8+i*X9+j*X10+k*X11+ l*X12+C \qquad (5)$$

Pooled model

$$Ypaddy = a*X1 + b*X2 + c*X3+d*X4 +e*X5 +C \qquad (6)$$

From Ypaddy, Ygrain was computed using the following equation-

$$Ygrain = Ypaddy \times Mw \times MF \qquad (7)$$

Where Ygrain = rice grain yield (t ha-1)
Ypaddy = fresh paddy yield (t ha-1)
Mw = moisture content in grain by weight (%)
a, b, c, d, e, f, g, h, i, j, k, l are the coefficients for X1, X2, X3, X4, X5, X6, X7, X8, X9, X10, X11, X12, respectively
X1----X12 for each state are the SH/SV at different calendar day
C = constant.

The dates of X1----X12 for each state are given in Table 3a and the corresponding coefficients are given in Table 3b.

	Calendar day for which SH/SV was used as input									
	Bihar	Chhattisgarh	Haryana	Karnataka	Odisha	Punjab	Telangana	UP	WB	Pooled
X1	158	212	189	143	181	145	180	157	145	105
X2	168	225	212	147	254	168	211	178	150	145
X3	172	252	235	155	257	173	248	194	180	155
X4	216	267	261	169	278	194	270	278	250	164
X5	224	272	297	201	287	211	280	301	287	180
X6	236	282	307	231	298	242	293			
X7	255	293		238		258	314			
X8	262	116		245		271				
X9	294	116		263		280				
X10						286				
X11						292				
X12						298				

Table 3a: Inputs for the rice yield model of 9 states and pooled model

	Coefficients									
	Bihar	Chhattisgarh	Haryana	Karnataka	Odisha	Punjab	Telangana	UP	WB	Pooled
a	1.73	-3.86	-12.25	7.83	-6.37	-3.94	-1.53	-17.14	8.89	-3.39
b	2.84	-4.03	9.05	-12.25	6.97	-3.79	0.58	8.98	-9.44	3.46
c	-1.25	7.39	-4.26	9.07	-2.24	-5.94	-1.93	10.81	4.80	1.46
d	-0.17	7.07	9.62	-6.62	12.02	0.45	3.52	14.58	-7.42	7.15
e	-1.37	-8.97	-6.36	1.37	7.065	3.79	-1.92	11.73	4.87	3.97
f	-0.53	0.87	-1.69	-0.30	-0.394	-5.00	6.34			
g	2.53	2.05		11.25		4.40	7.44			
h	-0.94			15.76		2.20				
i	0.08			1.52		4.52				
j						5.10				
k						2.72				
l						3.37				
C	-0.59	2.78	11.42	-17.89	-9.64	10.59	-3.65	24.74	3.30	-4.12

Table 3b: Coefficients of the regression model for the 9 states and pooled model

Among different states, the highest R2 of the daily model was obtained for Haryana state (0.87) and lowest was observed in Bihar (0.35). This could be due to the large number of observations (n=394) used for model development on Bihar state (Table 4).

State	*Correlation coefficient (r)*	*No of observation (n)*
Jharkhand	0.345	394
Chhattisgarh	0.618	26
Haryana	0.865	26
Karnataka	0.797	26
Odisha	0.599	42
Punjab	0.796	41

Telangana	0.536	33
Uttar Pradesh	0.551	33
West Bengal	0.644	22

Table 4: Correlation coefficient of the models for nine Indian state and the no of CCE data used for model development

The coefficient of determination (R2) for rice yield prediction was found to be significant at 95 % for all the 12 states of India with R^2 varying between 0.35 and 0.87 (Table 4).

5.4 Model Application and spatial yield map generation

Above developed models were applied as mentioned in the methodology section. Pixel wise paddy yield found to vary between 1 to 7.5 tha^{-1} in the six countries under study (fig 5). Country average yield was found to vary from 3.45 t ha-1 in Sri Lanka to 4.32 t ha^{-1} in Myanmar.

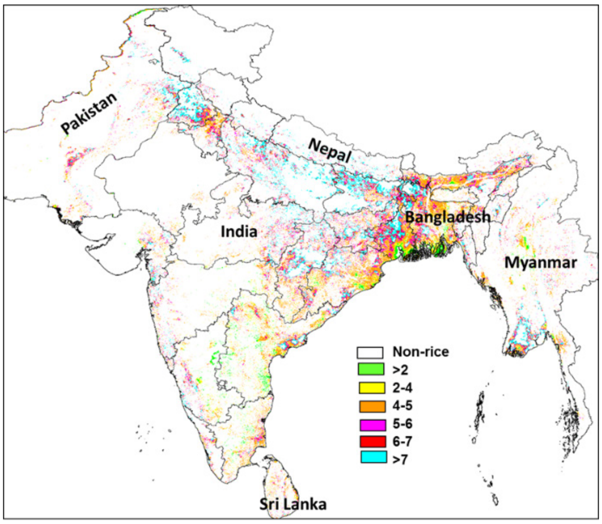

Figure 5. Rice grain yield (t ha^{-1}) of six South Asian countries at 2 km resolution using backscatter from SCASAT-1

5.5 Validation with reported yield

The models were validated with the reported yield (last five-year average) at state level in India and country level for other countries. For India at state level, the average deviation between the estimated yield with over the 12 states were found to be 6.05%. The correlation coefficient was found to be 0.95 while the RMSEs at state level were found to be 0.28 t ha^{-1} (11.24%), respectively (fig 5). Absolute difference between the estimated yield and that of reported yield remained less than 20 % in all states, maximum in Bihar (19 %) and minimum in Chhatishgarh (0.57 %).

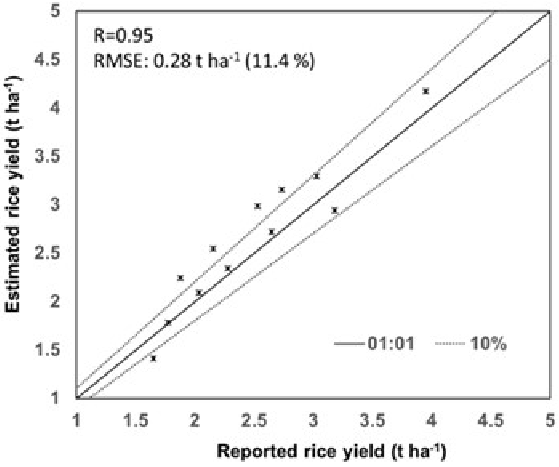

Fig 6. Comparison of state level rice yield estimated from the pixel model with the reported yield

The absolute difference was lowest in India (8 %) followed by Sri Lanka (-11 %) and maximum in Nepal (35 %) (Fig 7).

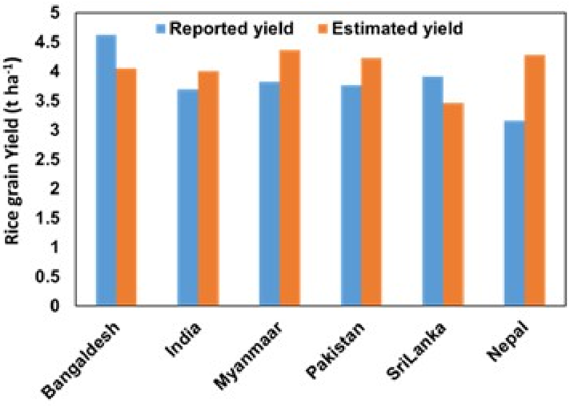

Fig 7: Comparison of estimated rice yield using SCATSAT-1 backscatter and reported rice yield at national level yield in six South Asian countries

6. CONCLUSIONS

This study showed the possibility of using high frequency and high resolution Ku-band back scattering coefficient for rice grain yield estimation at continental scale such as Asia. It can be concluded that owing to the high temporal resolution, the selection of bio-window was easy and accurate as compared to other data with low temporal resolution and can be used for national and state level yield forecasting in India and South Asia. The yield estimation can be further improved with the use of country-wise crop cutting data (especially for Nepal) for model development and validation.

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