CROP DISCRIMINATION USING MULTI-DATE RISAT-1 SAR SINGLE AND DUAL POLARIZATION DATA

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ABSTRACT: In India, large number of major crops area grown during kharif (rainy) season, which include rice, cotton, millets, pulses, groundnut etc. Getting cloud free data for their assessment is very difficult. Microwave SAR data provides an alternative. However, Multi-date SAR data analysis for classification of crops like Rice (transplanted) and Jute has been well established and operationalized. For other crops the research is still on using microwave data. The present study was carried out to explore the use of multi-date single and dual polarisation SAR data for assessment of rice and cotton crops. In this context, this study was conducted for Sirsa district of Haryana state, where cotton and rice are two major kharif season crops. RISAT 1 SAR data with both HH and HV polarisation was used for the study. The data acquisition dates were 23 June 2015, 18 July 2015, 12 August 2015 and 6 September 2015. The crop classification was done using ISODATA and Hierarchical Classification using multi-date RISAT HH and HV data with the ground truth collected during July. Both HH and HV signature profiles were also analysed. In case of rice, HH and HV data over four dates, showed similar pattern, though HV values were low. However, HH and HV profile patterns were significantly different in case of cotton. The classification accuracy (with 4 classes: rice, cotton, guar and other) was 84%, with kappa coefficient being 0.8331. However, when compared with DES estimates, the rice estimate was very close (-1.6% deviation), but the cotton area estimate was 22% lower than the DES estimate. Thus, though this study shows good accuracy of non-rice crop classification using dual polarisation SAR data, there is need for further work for improving the area estimation.

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1. INTRODUCTION

Synthetic Aperture Radar (SAR) data (airborne and space borne) has been used for crop discrimination and classification with the acceptable accuracy by various authors(Ainworth et. al., 2009, Freeman et al, 1994, Lee et al, 1999 and Skriver et al, 1994). During monsoon season due to cloud cover, there were difficulties in getting the optical data. In this case SAR data play a prominent role for crop discrimination. In India, among the kharif crops (from June to September) rice is a major food grain crop.

After the launch of first Indian microwave SAR satellite RISAT-1, SAR data has been used operationally for estimating the rice area in India. Assessment of crop classification using C band 3-date HH polarization SAR data and multi-date optical data has been used operationally for crop area monitoring in India (Ray et al. 2015, Parihar, 2002, Gosh K. 2014 and Gosh N 2008). In these studies, a time series profile analysis using various parameters like ground truth information about crop area, field size, sowing and harvesting time has been done.For area estimation of any major crop using remote sensing data in any area the competitive crop discrimination is also essential. Many studies have been conducted for the classification of RISAT-1 hybrid polarimetric data for various land features by various authors (Varsha et al, 2013 and2014, Mishra et al. 2013).

In the present study, the objective is to explore the use of multi-date single and dual polarization SAR data for assessment of rice and cotton crops. During the kharif season, cotton, gwar, bajra, rice and horticulture fruits crop are the major crop in Haryana (Satyawan et al. 2014).This study was conducted for Sirsa district of Haryana state where cotton and rice are two major Kharif season crops.

2. STUDY AREA

2.1 General Information:

The state of Haryana has a geographical area of 44.20 lakh hectare. About 86% of the geographical area is cultivable, of which 96% has already been brought under plough. About 80.5% of the total area is irrigated, through tubewells and an extensive system of canals.Sirsa, the north western most district of Haryana State with a total geographical area of 4270 sq. km is located between $29^{o}13'$: $29^{o}59'$ north latitudes and 74^{o} $30'$:$75^{o}7'$ east longitudes. This district is surrounded by Muktsar, Bathinda& Mansadistricts of Punjab in the north, Ganga Nagar &Hanumangarh districts of Rajasthanin West and South, Fatehabad and Hisar districts of Haryana in north east and southeast respectively.Sirsa district is under control of Hisar division and administratively divided intoseven development blocks namely Sirsa, Dabwali, Odhan, Baragudha, NathusariChoupta, Rania&Ellenabad.

2.2 Soil and Weather:

The type of soil is an essential factor for the growth of plants and crops in any region. The soil system has various criteria to classify the soils of a region such as geology, humidity, rainfall pattern, soil texture, soil salinity etc. The Sirsa district has two types of soils viz Sierozem and Desert soils. The sierozem soils are found in major parts of the district and desert soils are comparatively found in smaller part of the district especially in southern part of the district. Sierozem Soil are found in the areas where the normal annual rainfall varies from 300 to 500 mm. These soils vary from sandy loam to loamy sands in texture and are marginally fertile. These soils occur mainly in northern parts of the district i.e. Odhan, Baragudha & Sirsa blocks and parts of Dabwali, Nathusari Choupta & Rania blocks. Desert Soil are generally found in the areas where the annual rainfall is less than 300 mm. These soils are sandy and extensively cover southern parts of the district vizEllenabad block and parts of Dabwali, Rania & Nathusari Choupta blocks. As per the Soil Testing & Research Laboratory, Sirsa, the soils of the district are sandy to sandy loam in texture.

The weather of Sirsa district of tropical desert type arid and hot which is mainly dry hot summer and cold winter except during monsoon period season when moist air of oceanic origin penetrate into the district. There are four seasons in a year. The hot weather season starts from mid-March to last week of the June followed by the south-west monsoon which lasts upto September. The transition period from September to October forms the post-monsoon season. The winter season starts late in November and remains upto first week of March.

2.3 Major Crops:

In Haryana, there are two main seasons for crops, Monsoon (from May to October) and Winter (November to April). In Monsoon season, major crops are rice, cotton, sugarcane, Gwar and Bajra (Pearl Millet). However in Winter season, major crops are wheat, mustard, Black gram and barley. In Sirsa district major crops grown as rice, cotton during monsoon season wherever wheat and mustard grown in winter season.

3. DATA USED

3.1Microwave Data:

In microwave satellite data, multi-date RISAT-1 (Radar Imaging satellite, which is an active microwave remote sensing satellite with C-band Synthetic Aperture Radar (SAR)) dual polarization modes (HH and HV) have been used. It operates in four different modes, Coarse Resolution ScanSAR mode (CRS), Medium Resolution ScanSAR mode (MRS), Fine Resolution Strip map mode-1 (FRS-1) and Fine Resolution Strip map mode-2 (FRS-2). This satellite data is available in every 25 days for the same area.Four dates from June to September, 2015 (23 June, 18 July, 12 August and 6 September 2015) of RISAT-1 MRS (HH and HV) data have been used.

3.2Optical Data:

Resourcesat -2 with enhanced capabilities after Resourcesat-1 launched on 17^{th} October 2003. It has three cameras mountes on a single platform with a high resolution sensor LISS-IV, medium resolution LISS-III and a coarse resolution AWiFS. Resourcesat-2 is a three axes stabilized body and carries three optical cameras. The orbit is similar to that of Resourcesat-1, i.e. the satellite operates in a circular, sun-synchronous, near polar orbit with an inclination of 98.69 deg. at an altitude of 817km. the satellite takes 101.35 minutes to complete one revolution around the earth and completes about 14 orbits per day. The entire earth is covered by 341 orbits during a 24 day cycle. AWiFS scene for October 2015 is also used for reference. The AWiFS sensor on-board resourcesat-2 has enhanced capabilities compared to the AWiFS of Resourcesat-1 in terms of radiometric resolution (12 bits vs. 10 bits.) with revisit period of 5 days. The data is acquired in four spectral bands, three in visible and in NOR (VNIR,

B2 B3 and B4) and one in short wave infrared (SWIR B5). The AWiFS camera is realized in two electro-optic modules viz. AWiFS –A and AWiFS –B, providing a combined swath of 740km.

Table 1: Details of Used Satellite Data (Microwave and Optical) remote sensing

S.No.	Satellite and Sensor	Dates of Data Acquisition	Path and Row/Mode /Spectral Bands
1	RISAT-1 (MRS)	23 June 2015, 18 July 2015, 12 August 2015, 6 September 2015	HH and HV
2	Resourcesat-2 (AWiFS)	October 8, 2015	93, 48, B2 (0.52-0.59), B3 (0.62-0.68), B4 (0.77-0.86) B5 (1.55-1.70)

3.3 Ground Truth:

Ground truth (GT) is an essential component for remote sensing data analysis. Ground truth data collection is done to gain reality from the ground on a selected period of time. In case of crop area assessment, vegetative period of crop is the time to perform ground truth. There are certain characteristics of a proper ground truth, viz. self-location, information about crop field, field size, crop stage, field photographs and field sketch and other ancillary information as well, date of sowing and expected date of harvesting. Ground truth is completed with initiative Smartphone based GT collection. An Android based application was developed by National Remote Sensing Centre (ISRO), as per the requirement of Mahalanobis National Crop Forecast Centre MNCFC. MNCFC provided on-site training to State Agriculture Department Officials for GT collection using Smartphones. The ground truth points used in this study have been collected by State Agriculture Department officials using Smartphones provided by MNCFC. The GT information directly comes to ISRO/Bhuvan server, which can be downloaded using User login. Mostly field size for rice is found as 500x500m to 2000x2000m and for cotton is 1000mx1000m. Crop growth stage is found mostly vegetative and some of them were tillering. Crop health condition was observed as good and crop cover on ground was found mostly as 61-80 %. Date of sowing for rice was observed as June to July 2015 and date of harvesting was found as October to November 2015. For cotton, sowing was observed as May 2015. Soil condition was found mostly as flooded for rice fields.

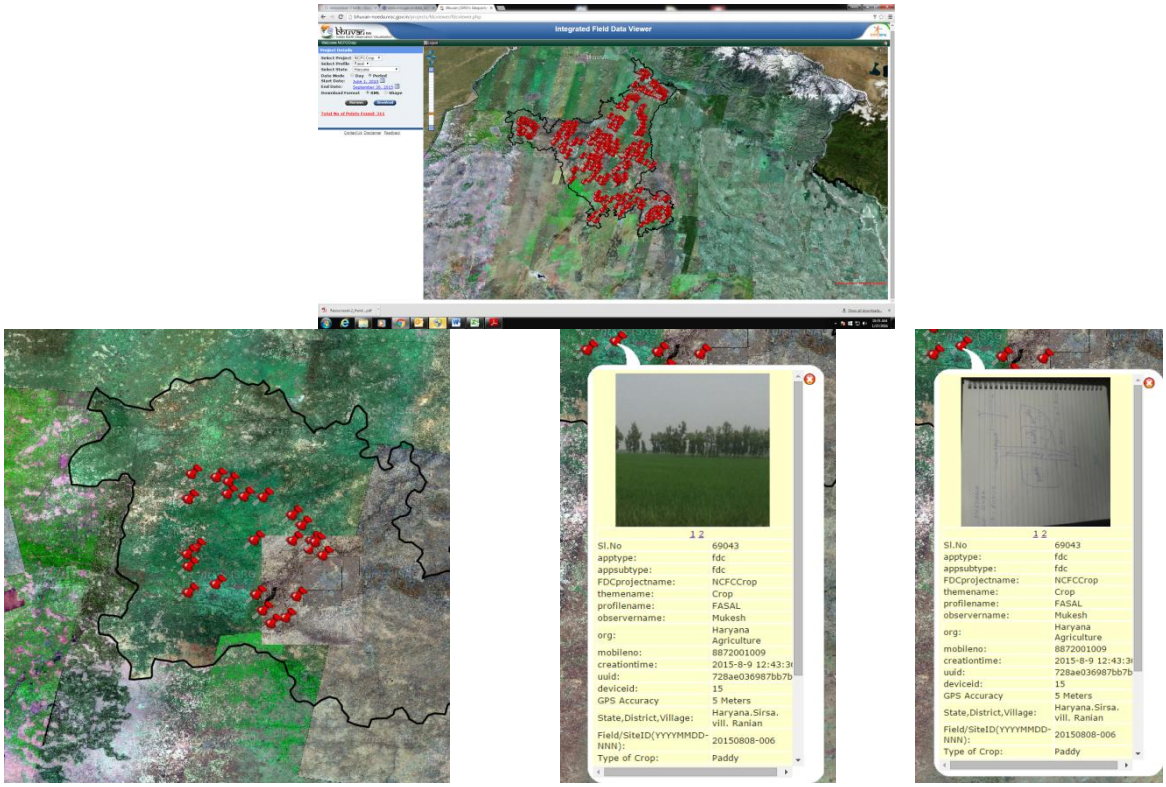

Figure 1: Ground truth data for Haryana (top), Sirsa (Bottom left), attribute table with photograph of crop (middle) and of hand sketch (extreme right).

4. MATERIAL AND METHODS

4.1 Data Pre-processing:

For microwave remote sensing data (RISAT-1) MRS HH and HV data, pre-processing was performed i.e. speckle removal, Image to image registration, and multi date (four dates) image stacking. These steps were done using FASALSoft 1.0 software developed by Space Applications Centre (SAC) for data processing. Layer stacked image has been prepared and imported into the img format for further analysis which was carried out in ERDAS imagine software.

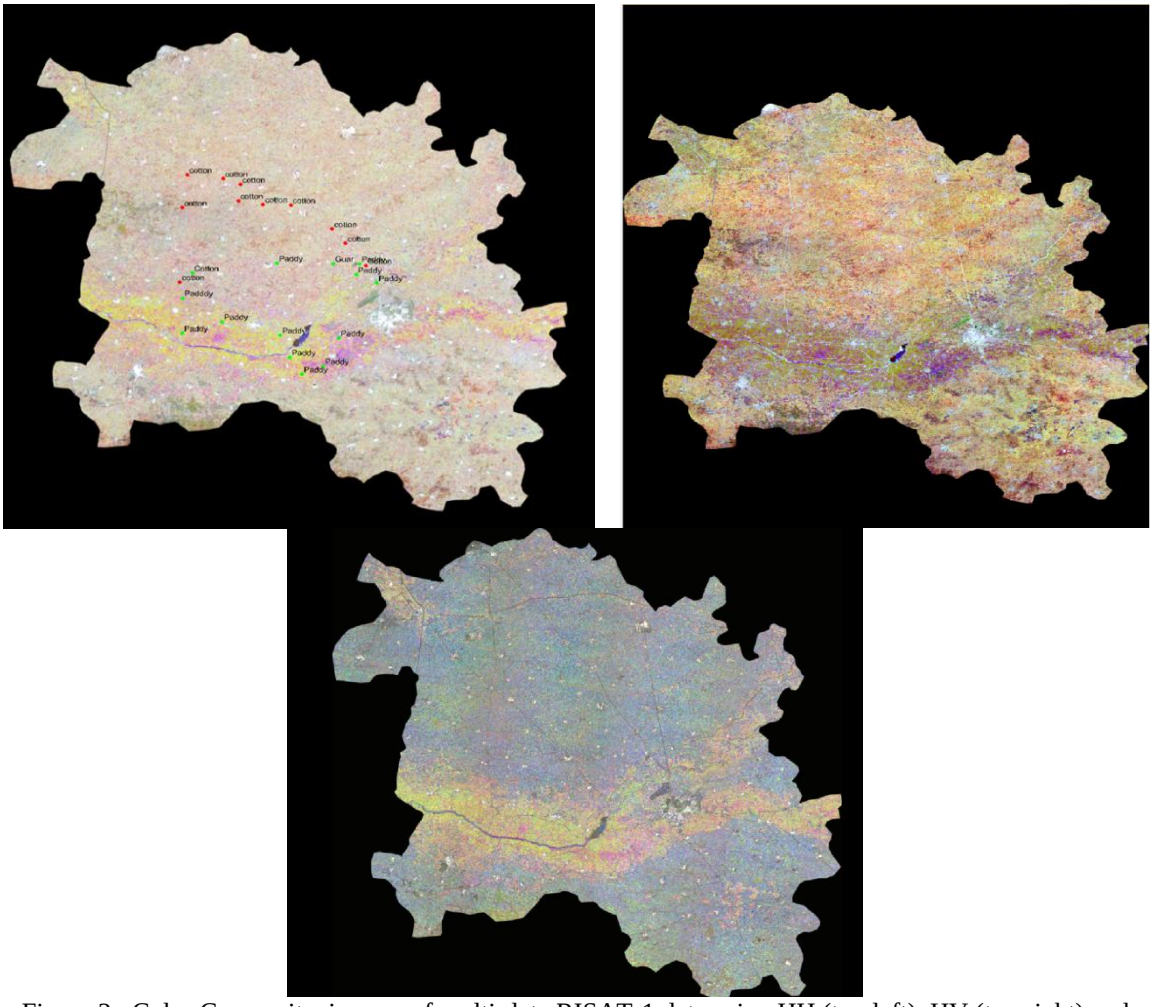

Figure 2 : Color Composite images of multi-date RISAT-1 data using HH (top left), HV (top right) and HH/HV (bottom) data (Date 1-R, Date 2-G,Date 3-B) with overlaid GT points

4.2 Classification

The crop classification was done using ISODATA and Hierarchical classification approach using multi-date RISAT-1 HH data.

4.2.1 Hybrid Classification: Iterative Self organizing Data Analysis Technique (Iso-Data) clustering classifier was used in unsupervised classification approach and class of interest were identified using ground truth information for major Crops like Rice, Cotton etc. with other land cover classes. Mask of mixed classes was prepared and image under the mask was reclassified. The reclassification process was continued till the classes of interest were segregated. To improve the accuracy of classification, mask of non-agricultural classes such as urban, forest and wastelands was prepared and used at the time of classification. After the unsupervised classification, classes for crops were prepared based on the signature generated using the ground truth and steps were repeated until the satisfaction appears. Ground truths points (around 25) were used for major crops like Cotton and rice. Analysis of Remote sensing data for Sirsa is showing that Rice and cotton are the major crops are found duringkharif season. Unsupervised classification was performed by taking 50 classes on RISAT-1 MRS HH data.

Signatures were generated using the ground truth collected for rice, cotton and guar. Classified map were generated for rice and cotton for the study area.

4.2.2 Hierarchical Classification: FCC was generated after pre-processing the data. Crop Classification was done using four dates of RISAT-1 SAR images by passing first date, second date and third date images through red, green and blue colour filters or second date, third date and fourth date images through red, green and blue colour filters respectively. The output colour of each category crop (rice) depends on the percentage mixing of each colour which again depends on the backscatter value from each date image. For first date rice or early rice (rice having transplantation date near to the first date of image) the backscatter value for the first image is low due to water background while for rest two images the value is high which results into more percentage of green and blue color while less of red colour which ultimately mixes into cyan color.

For second date or normal rice (rice having transplantation date near to the second date image) the backscatter values for first date and third date images is high while for second date image the value is low due to water background which results into more percentage of red and blue color while less of green color which ultimately mixes into magenta color.

For third date or late rice (rice having transplantation date near to the third date image) the backscatter values from first date and second date images are high while for the third date image the value is low which results into more percentage of red and green color while less of blue which ultimately gives yellow color.

For urban all the three dates having high backscatter value because of more roughness and other factors which results into equal mixing of each color that's why results into white color.

For water each images show less backscatter values which results into less amount or almost no proportion for each color ultimately results into black color.

Multi date SAR False color composite is now classified by taking the sufficient number of training sets or samples on or near to the ground truth sites. The statistical values of each sample set are analysed. Decision rule based models have been generated for sown rice areas as mentioned in methodology. Crop map has been generated.

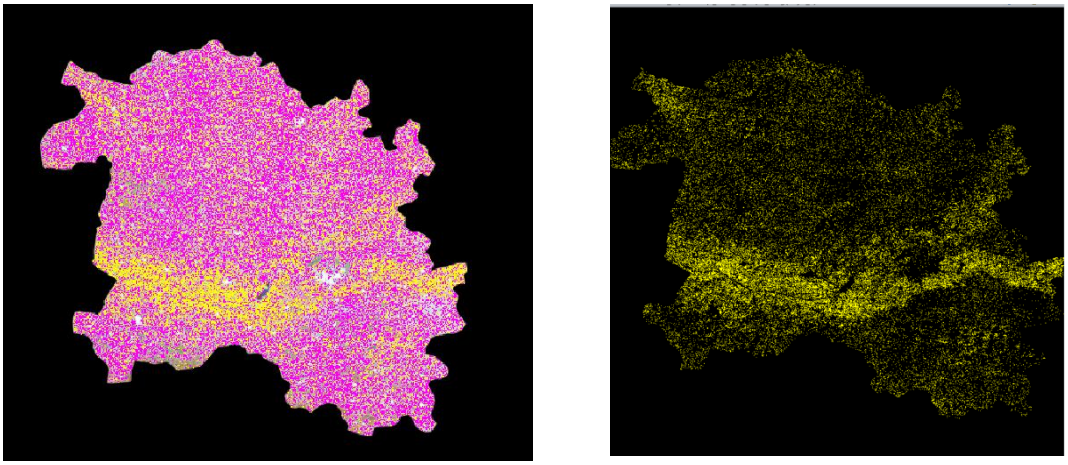

Figure 3: Classified images of RISAT-1 HH data using Hybrid (left, Cotton (pink) and rice(yellow)) and Hierarchical Classification (right)

4.2.3 Profile Generation: Comparison of the backscattering coefficients (σ0 db) values for dual polarization (HH, HV and HH/HV data) have been made for different four dates (D1- 23 June, D2-18 July, D3- 12 Aug and D4- 6 Sep) for rice and cotton. Two samples (S1 and S2) have been taken for HH and HV for rice. Total eight signatures profiles were studied for HH, HV and HH/HV. Error bar is also plotted for each sample in each date.

For rice, in two different samples in HH polarization the transplanting date may be different due to this the minimum backscatter was found in the first date and second date. This also means that in this area rice transplanting was done in June end and mid-July. In HV polarization, the similar patterns were observed for both samples as in HH polarization but exhibits the lowest with a bias of around 10 db values with HH component.

For cotton, two profiles were studied in HH and HV data. The pattern for the both the profiles are similar with a bias of 10 db values.

In HH/HV polarization, the profiles for rice is also similar to HH (S1) but within the range of HV. For Cotton, the trend is almost constant as in HH and HV the trend is found similar with the bias values of 6 to 10 db.

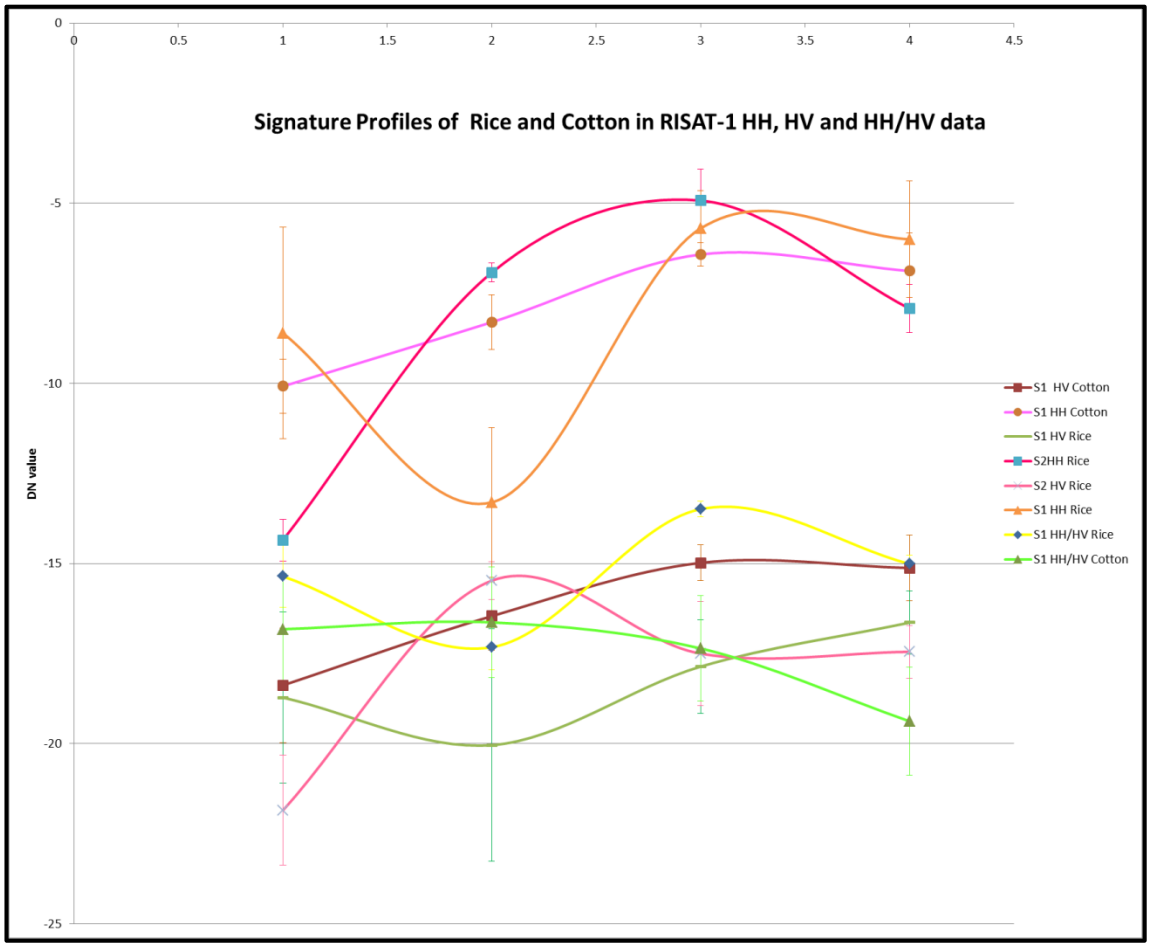

Figure 4 : Signature Profiles of Rice and Cotton in RISAT-1 HH, HV and HH/HV data

4.3 Backscatter Values

Table 4 shows the mean σ^0 db values for each class for different dates (From June to September 2015). As it is clear from the table that there is a clear separation of mean values of various classes found but it is difficult to classify the data on backscatter alone because standard deviation of various class feature is high and it overlaps with the mean values of other features.

Table 6: σ^0 db Values for RISAT-1 dual polarization (HH, HV and HH/HV) data for different dates

	HH				HV				HH/HV			
Class	D1	D2	D3	D4	D1	D2	D3	D4	D1	D2	D3	D4
Water	-19.8	-19.4	-16.4	-17.6	-25.1	-24.4	-21.7	-23.7	-22.1	-19.0	-19.6	-18.8
Urban	-0.2	-0.8	-1.9	-1.2	-13.5	-13.5	-12.3	-14.1	-9.8	-9.5	-8.6	-9.4
Rice	-12.6	-15	-4.5	-4.0	-20.3	-22.7	-17.7	-16.5	-15.4	-17.3	-13.5	-15.0
Cotton	-10.6	-7.4	-4.9	-9.1	-13.5	-15.1	-14.1	-13.9	-14.6	-16.3	-15.0	-17.6
Guar	-10.3	-8.8	-5.7	-10.6	-22.4	-16.0	-14.7	-17.4	-19.5	-16.6	-16.2	-16.8

5. ACCURACY ESTIMATION

5.1 Contingency matrix:

5.1.1 RISAT-1 HH data: Contingence matrix has been generated for four major classes Rice (2 types), Cotton (2 types), Guar and other (Waterbody and Urban). The producer and user accuracy is calculated as mentioned in below table using RISAT-1 HH data. User accuracy is fairly good in case of Waterbody, Rice, Urban and Cotton. Producer accuracy is high in case of Urban and Rice. In case of Cotton, producer accuracy was found as 71-72%. Overall accuracy was found as 84% with kappa coefficient is 0.8331.

Table 2: Contingency Matrix for Rice, Cotton with land features using RISAT-1 HH data

Contingency Matrix	Guar	Urban	Rice1	Rice2	Cotton1	Cotton2	Water body	Row total	Users Accuracy
Guar	17	0	0	0	2	11	0	30	57%
Urban	0	380	1	2	2	2	90	477	80%
Rice1	0	2	346	15	45	52	3	463	75%
Rice2	0	0	0	289	0	4	7	300	96%
Cotton1	4	0	14	2	163	6	28	217	75%
Cotton2	10	0	0	0	16	195	8	229	85%
Waterbody	0	0	0	0	0	0	340	340	100%
Column Total	31	382	361	308	228	270	476	2056	
Producer's Accuracy	55%	99%	96%	94%	71%	72%	71%		

Overall accuracy: 84% , Kappa Coefficient: 0.8331

5.1.2 RISAT-1 HV data: Contingence matrix has been generated for four major classes Rice (2 types), Cotton (2 types), Guar and other (Waterbody and Urban). The producer and user accuracy is calculated as mentioned in below table using RISAT-1 HH data. User accuracy is low (38-77%) in case of Guar, Urban and Rice. Producer accuracy is low (41%) in case of water body. In case of Cotton, producer accuracy was found as 73-78%. Overall accuracy was found as 64% with kappa coefficient is 0.4307.

Table 3: Contingency Matrix for Rice, Cotton with land features using RISAT-1 HV data

Contingency Matrix	Guar	Urban	Rice1	Rice2	Cotton1	Cotton2	Water body	Row Total	Users Accuracy
Guar	31	2	4	0	14	5	7	63	49%
Urban	1	264	5	3	2	9	412	696	38%
Rice1	1	0	228	6	2	0	58	295	77%
Rice2	0	0	11	28	3	1	5	48	58%
Cotton1	2	0	2	2	99	9	12	126	79%
Cotton2	2	0	0	3	15	85	13	118	72%
Waterbody	0	9	0	0	0	0	354	363	98%
Column Total	37	275	250	42	135	109	861	1709	
Producer's Accuracy	84%	96%	91%	67%	73%	78%	41%		

Overall Accuracy 64%; Kappa 0.4307

5.2 Separability Analysis

5.2.1 RISAT-1 HH data: Separabilityanalysis has been done using transform divergence of major four classes: Rice (2 types), Cotton (2 types), Guar and other (Waterbody and Urban) using RISAT-1 HH data. Classes can be studied as follows:

1. Poor Separable Less than 1700
2. Fairly good greater than 1700 and less than 1900
3. Separable greater than 1900

Lowest separability (1491) was seen between the crops (Cotton). As two types of rice and cotton classes has been selected. Mostly all the classes were found to be separable from each other except guar crop.

Table 4: Separability Analysis for different classes using RISAT-1 HH data

	Waterbody	Guar	Urban	Rice1	Rice2	Cotton1	Cotton2
Waterbody	0	2000	1999	2000	1997	2000	2000
Guar	2000	0	1999	2000	2000	1830	1348
Urban	1702	1999	0	1988	1999	1891	1778
Rice1	2000	2000	1988	0	1999	1850	1969
Rice2	1997	2000	1999	1999	0	1788	1895
Cotton1	2000	1830	1999	1850	1788	0	1491
Cotton2	2000	1348	1999	1969	1895	1491	0

5.2.2 RISAT-1 HV data: Similarly separability analysis has been done using transform divergence of major four classes: Rice (2 types), Cotton (2 types), Guar and other (Waterbody and Urban) using RISAT-1 HV data. Classes can be studied as earlier mentioned in section 5.2.1. Minimum separability was found (933) between the crops (Cotton). Here Rice is also not separable from Guar, Urban, and Cotton.

Table 5: Separability Analysis for different classes using RISAT-1 HH data

	Waterbody	Guar	Urban	Rice1	Rice2	Cotton1	Cotton2
Waterbody	0	2000	1455	1991	1745	2000	2000
Guar	2000	0	1942	1876	1895	1419	1211
Urban	1455	1942	0	1896	1178	1597	1676
Rice1	1991	1876	1896	0	1525	1939	1622
Rice2	1745	1985	1178	1525	0	1770	1692
Cotton1	2000	1419	1597	1939	1770	0	933
Cotton2	2000	1211	1676	1622	1696	933	0

By Separability analysis it was clear that Rice classes were clearly separable using HH data from other classes in comparison to HV data.

5.3 Area Estimation

The crop area estimated using multi-date RISAT 1 HH data is given in Table 7. Though the estimated rice area matched very well (1.6% deviation) with government estimates, there was large underestimation (22%) for cotton area.

Table 7: Area Statistics of Rice and Cotton of Sirsadistrict using RISAT-1 HH data

Crop	Remote Sensing Based Area (000'ha)	DES average (3 years) Area (000'ha)	Relative Deviation (%)
Rice	62.2	63.2	1.6
Cotton	154.9	199.7	22

6. CONCLUSION

The present study focused on the crop (rice and cotton) discrimination using multi-date RISAT-1 SAR (HH and HV) data for Sirsa district of Haryana for the year 2015. Classification was done using ISODATA and Hierarchical Classification using multi-date SAR data with the ground truth collected during July. Signature profiles were also studied for HH and HV data. In case of rice, HH and HV data over four dates, showed similar pattern, though HV

values were low. However, HH and HV profile patterns were significantly different in case of cotton. The classification accuracy (with 4 classes: Rice (2 types), Cotton (2 types), Guar and other) was 84%, with kappa coefficient being 0.8331 using HH data. The classification accuracy was found 64 % with kappa coefficient 0.43067 using HV data. Compared with DES estimates, the rice estimate was very close (-1.6% deviation), but the cotton area estimate was 22% lower than the DES estimate. In this study it was found that for rice classification using RISAT-1 HH data can achieve good accuracy (84%) wherever for non-rice crop classification using dual polarisation SAR data, there is need for further work for improving the area estimation.

REFERENCES

Ainsworth, T. L., J. P. Kelly, and J.S. Lee, 2009. Classification comparisons between dual-pol, compact polarimetric and quad-pol SAR imagery. ISPRS Journal of Photogrammetry and Remote Sensing, 64, pp. 464-471.

DES, 2015. Agricultural Statistics at a Glance 2014. Directorate of Economics and Statistics, Department of Agriculture and Cooperation. Ministry of Agriculture. Government of India. Oxford University Press. pp.452.

Freeman, J., J. D. Villasenor, H. P. Klein, and J. Groot, 1994.On the use of multi-frequency and polarimetric radar backscatter features for classification of agricultural crops, Int. J. Remote Sensing, 15(9), pp. 1799-1812.

Ghosh, K., Balasubramanian, R., Bandopadhyay, S. Chattopadhyay, N., Singh, K.K. and Rathore, L.S., 2014. Development of crop yield forecast models under FASAL- a case study of kharif rice in West Bengal.. J. Agromet., 16 (1), pp. 1-8.

Ghosh, N., Chakravarty, S. and Bhatt, Y., 2008. Crop supply forecasting for food management: A review of practices, developments and options. Agri. Situation India, pp. 331-340.

Lee, J. S., M. R. Grunes, and G. De Grandi, 1999b.Polarmetric SAR speckle filtering and its implication on classification. IEEE Trans.Geosci. Remote Sensing. 37, pp. 290-301.

Misra T., S. S. Rana, N. M. Desai, D. B. Dave, Rajeevjyoti, R. K. Arora, C. V. N. Rao, B. V. Bakori, R. Neelakantan and J. G. Vachchani. 2013. Synthetic Aperture Radar payload on-board RISAT-1: configuration, technology and performance. Current Science, 104(4), pp. 446 – 461.

Parihar, J.S. &Dadhwal, V.K., 2002. Crop production forecasting using remote sensing data: Indian experience: Proceedings of the ISPRS Comm. VII Symposium Resource and Environmental MonitoringHyderabad, India,Vol. 34, Part 7, pp. 1–6.

Raney, R.K., 2007. Hybrid-polarity SAR architecture. IEEE Trans. Geosci. Remote Sens., 45(11) pp. 3397-3404.

Ray, S. S., Mamatha, S, Neetu and Gupta, S., 2015. Use of remote sensing in crop forecasting and assessment of impact of natural disasters: operational approaches in India. Crop monitoring for improved food security. Proceedings of the Expert Meeting Vientiane, Lao People's Democratic Republic, RAP Publication 28, FAO & ADB, pp. 111-121.

RISAT-1 Data Products Formats. 2013. http://nrsc.gov.in/assets/pdf/format2.pdf

Satyawan , M. Yadav, R.S. Hooda, 2014. Cropping System Analysis Using Geospatial Approach: A Case Study of Sirsa District in Haryana, India. International Journal of Science and Research (IJSR) 3(9).

Skriver, H., T. S. Morten, and A. G. Thomsen, 1999. Multitemporal C- and L-band polarimetric signatures of crops, IEEE Transactions on Geoscience and Remote Sensing, 37(5), pp. 2413-2429.

Turkar, V., Shaunak De, G. G. Ponnurangam, RinkiDeo, Y. S. Rao, A. Das. 2014. Classification of RISAT-1 Hybrid Polarimetric Data for Various Land Features. Asia Pacific Conference on Synthetic Aperture Radar, At Tsukuba, Japan.

Turkar, V., Shaunak De, Y. S. Rao, A. Bhattacharya and A. Das. 2013. Comparative Analysis of classification accuracy for RISAT-1 Hybrid Pol. Data. Proc. IEEE IGARSS.