

# Integration of ERS-2 SAR and IRS-1D LISS-III Image Data for Improved Coastal Wetland Mapping of southern India

P. Shanmugam\*, Yu-Hwan Ahn\*, S. Sanjeevi\*\*, and A.S. Manjunath\*\*\*

Korea Ocean Research and Development Institute\*

Centre for Geoscience and Engineering, Anna University, Chennai, India\*\*

National Remote Sensing Agency, Hyderabad, India\*\*\*

**Abstract :** As the launches of a series of remote sensing satellites, there are various multiresolution and multi-spectral images available nowadays. This diversity in remotely sensed image data has created a need to be able to integrate data from different sources. The C-band imaging radar of ERS-2 due to its high sensitivity to coastal wetlands holds tremendous potential in mapping and monitoring coastal wetland features. This paper investigates the advantages of using ERS-2 SAR data combined with IRS-1D LISS-3 data for mapping complex coastal wetland features of Tamil Nadu, southern India. We present a methodology in this paper that highlights the mapping potential of different combinations of filtering and integration techniques. The methodology adopted here consists of three major steps as following: (i) speckle noise reduction by comparative performance of different filtering algorithms, (ii) geometric rectification and coregistration, and (iii) application of different integration techniques. The results obtained from the analysis of optical and microwave image data have proved their potential use in improving interpretability of different coastal wetland features of southern India. Based visual and statistical analyzes, this study suggests that brovey transform will perform well in terms of preserving spatial and spectral content of the original image data. It was also realized that speckle filtering is very important before fusing optical and microwave data for mapping coastal mangrove wetland ecosystem.

**Key Words :** Radar, Multisensor, Wetland, Pitchavaram, Coleroon.

## 1. Introduction

The role of coastal wetlands as a valuable natural resource has been receiving increased attention at international, regional and local levels. In sub tropical coastal environments, the mangrove wetlands play a major role in supplying organic matter to coastal marine

ecosystem and also in protecting the coast from erosion and other natural disasters (Shanmugam, 2002). The coastal mangrove wetlands form habitats for many biological communities and at the same time often affected by various natural and anthropogenic factors leading to degradation of the habitats (Lundin *et al.*, 1993; Viles, 1988). The growing pressure on the coastal areas as a result of expanding population and increasing

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commercial, industrial, and other developmental activities has clearly indicated the urgent need to manage these coastal areas in an optimal and judicious manner. In the recent years, the optical remote sensing systems have proven useful in providing information about coastal wetlands and at the same time limitations in the abilities of such sensors to discriminate wetland features especially estuarine wetlands from adjacent land cover types. More than 20 years of operation of optical remote sensing satellites have shown that it is very difficult to obtain cloud free imagery especially in coastal regions that are frequently covered by cloud. In contrast, microwaves are capable of penetrating clouds and are actively sent by the antenna. So that the radar sensor is independent of weather or day light (Genderen and Pohl, 1994).

The launching of ERS-2 SAR radar satellite in 1995 was a significant achievement of the earth resources scientific community in these efforts to improve operational monitoring of land cover changes in the coastal regions that are frequently affected by cloud coverage and atmospheric problems. Thus, the combination of microwave and visible and infrared image data provides valuable tools for mapping such complex coastal features with high accuracy (Ramsey *et al.*, 1998). In the first instance, cloudy areas in optical imagery can be replaced by radar data. Secondly, the optical data can serve substituting no data areas in SAR data, *i.e.*, radar shadow. Thirdly, the different data sets provide complementary information due to the differences in wavelength and their physical characteristics. While optical data contain the reflectance of ground cover in visible and near infrared, the radar is very sensitive to the surface roughness and moisture content of the illuminated targets. Thus the combined use of multisensor data visualizes the valuable additional information of the earth surface features and shows the potential to overcome the cloud cover problems. Image

fusion is one of the possibilities of combining disparate images to produce a new data set containing the characteristics of both input images (Genderen and Pohl, 1994). The classification can be performed on the fused image of optical and radar data in order to achieve more accuracy (Ramsey *et al.*, 1998).

However, for synthetic aperture radar images, speckle noise constitutes one of the main obstacles. Lee (1986) describes speckle as a "form of multiplicative noise" in the sense that the noise level increases with the magnitude of radar back scattering. Speckle is a dominating factor in SAR imagery, as is well known. It is less well known that speckle carries valuable information about the imaging system itself, and about all digital analysis steps between the original image and any given image product (Henderson and Lewis, 1998). According to Trevett (1986), speckle causes a grainy appearance in SAR images and is an effect of surface roughness and system factors on image production. It is a phenomenon of coherent scattering and accounts for the interference contribution of individual scatters (e.g. individual leaves from vegetated areas). The interference of these returning waves causes variation in the grey levels in the adjacent pixels in the image and produces the speckle. Numerous studies investigated various SAR filtering techniques applied to spaceborne SAR data (Lee, 1981; Paudyal, Aschbacher, 1993; Hagg and Sties, 1994). It is therefore essential to remove the speckle noise before going for any interpretation or classification of SAR data by filtering the speckle (Durand *et al.*, 1987). This study aims to (1) investigate the complementarity of the use of multisensor data set of optical (IRS-1D LISS-III) and microwave (ERS-2 SAR) data for mapping the complex coastal mangrove wetland features of southern India, and (2) evaluate the suitability of certain speckle suppression and data integration techniques for improved mapping of the study region.

## 2. Study Area and Data Products

The Pitchavaram coastal wetland is situated on the southeastern coastal part of Peninsular India and represents a heterogeneous mixture of mangrove wetland ecosystem. It lies between the coordinates of latitude  $11^{\circ} 20' 00''$  N to  $11^{\circ} 30' 00''$  N and longitude  $79^{\circ} 45' 00''$  E to  $79^{\circ} 51' 00''$  E. It is an estuarine type of mangrove wetland ecosystem, situated at the end of a canal called Uppanar, which is a distributory of the Coleroon River. The Pitchavaram mangroves are connected to the Vellar estuary in the north and Coleroon estuary in the south along with the Killai lagoon by a well-developed backwater system (Fig.1a). This area is often referred to as the Vellar-Coleroon estuarine complex, which includes various wetland features such as mangroves, marsh, scrub, mudflat, aquaculture, lagoon, beach, and other associated land cover features such as agricultural vegetation, plantation and fallow lands, etc. Concerning data products, SAR image was acquired by the European Space Agency's (ESA) ERS-2 satellite on 19 November 1997 and processed to a 16-bit, 3 look standard ERS-2 Precision Image (SAR.PRI) with a pixel size of  $12.5\text{m} \times 12.5\text{m}$ ,

covering an area of approximately  $100 \times 100 \text{ km}^2$ . A subscene covering the study site was selected for detailed analysis (Fig.1b). Similarly, IRS-1D LISS-III image data was acquired on 14 January 1998 and a subset of the same was analyzed (Fig. 1a). In addition to this study, a field investigation was carried out in different parts of the study site with the help of global positioning system (GPS) to collect ground information about various mangrove communities and other wetland features so that later the ground and resulting image information could be compared.

## 3. Implementation of Speckle Suppression Algorithms

There have been many speckle suppression algorithms developed to reduce the speckle noise in the radar images. These algorithms are divided into two main categories that are non-speckle specific (median filter) and speckle specific (used in this study). The non-speckle specific filters do not explicitly take into account the multiplicative noise model of speckles, where as speckle specific filters do so (Lee, 1986). The use of radar images for further digital interpretation and classification purposes requires the spatial filtering algorithms that preserve edges, textures, and smoothing of homogeneous areas. A few of these filters include: Median filter, Leesigma filter, Lee filter, Gamma filter, Frost filter and Local region filter. Further details about filtering algorithms may be seen in Paudyal and Aschbacher (1993) or Shi and Fung (1994). The above speckle suppression filters were implemented and tested on the subscene of ERS-2 SAR image data of the study site (Fig. 2). The filtered images were examined based on visual and statistical procedures. In general, successful speckle filtering has to accomplish the following requirements: reduction of variance in homogeneous areas, preservation of edges and linear

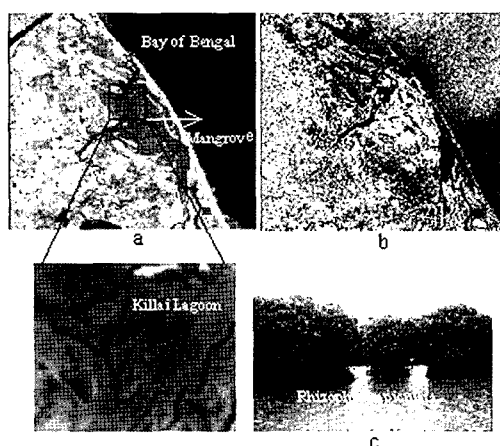


Fig. 1. (a) IRS-1D LISS-III (band-321) of the Pitchavaram study site, (b) ERS-2 SAR image, and (c) *Rhizophora apiculata*.

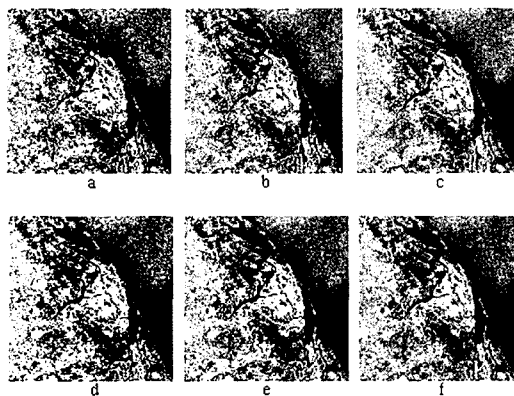


Fig. 2. Results of speckle suppression algorithms as applied to original SAR data. (a) Local region filtered image, (b) Frost filtered image, (c) Lee filtered image, (d) median filtered image, (e) Leesigma filtered image, and (f) gamma filtered image.

features, exclusion of point scatterers, preservation of spatial variability, avoidance of artifacts (Shanmugam, 2002). The successful of these filters also depend on the window size and number of iterations.

#### 4. Radiometric and Geometric Correction

Radiometric and geometric corrections play an important role in satellite image analysis because of having various radiometric and geometric distortions being encountered during the image acquisition. The purpose of geometric correction is to compensate for the distortions introduced by certain factors so that the corrected image will have the geometric integrity of a map. This is necessary for many applications before the information can be extracted. It is understood that the satellite data (IRS-1D LISS-III) are radiometrically corrected at ground station. Hence, no further radiometric correction was made for IRS-1D LISS-III data. In the case of SAR PRI image data, a vertical

antenna pattern of ERS-SAR causes distortions in radar pixel intensities in range directions. Usually, this appears as gradual increase and then decrease in mean column grey-levels. The antenna pattern correction compensates for this non-uniform illumination of the target in range direction. It is, however, SAR PRI product from SAR data archival facilities at National Remote Sensing Agency, India, was delivered system corrected, *i.e.*, the images had been calibrated and corrected for the SAR antenna pattern. Hence, no further corrections for the same were made. Subsequently, 16 bit SAR data was linearly rescaled into 8 bit data to be able to compare with 8 bit optical data. The speckle filtering algorithms were then implemented and tested on SAR image data in different levels of processing.

After necessary processing was made on the original SAR data, it needed to be geometrically corrected because the side looking SAR is highly sensitive to the terrain variations. The filtered images were subjected to rectification with respect to topographic map. For rectification of SAR image data with respect to map, sixteen GCPs were selected so that the RMS error achieved was quite satisfactorily less than one pixel (RMS error: 0.868 to 0.892 for all images). A careful selection of same GCPs in all filtered images would result the above values because the selection of GCPs in SAR images is difficult compared to optical image data. Subsequently, the subscene of IRS-1D LISS-III image was then coregistered to the rectified SAR images and resampled to 12.5m. The RMS error was found to be less than one pixel level in all images. Finally, the rectified images were integrated using different fusion techniques and the results were compared based on visual, statistical procedures (Fig. 3). The resulting images have brought out various mangrove communities and other wetland features as well while removing the cloud cover which were present in the optical image data.

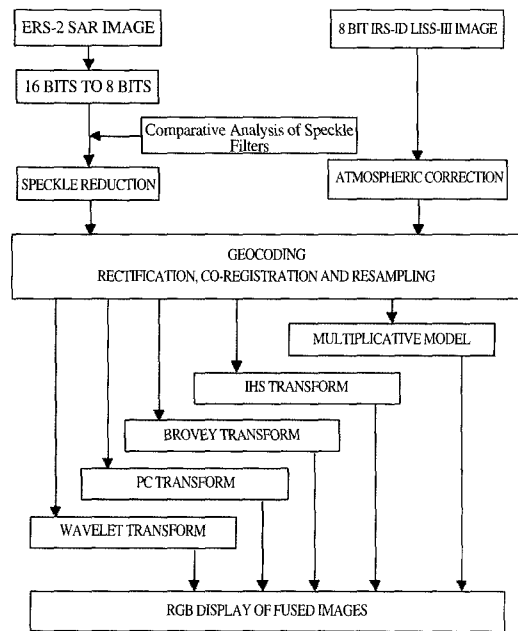


Fig. 3. Outline of methodology adopted to obtain integrated images using different integration techniques.

## 5. Integration Techniques

Integration of data from different sensors has been published in several applications (Genderen and Pohl, 1994). The motivation behind data integration is to generate an interpretation of the scene not obtainable with data from single sensor. It is interesting to combine data from optical and microwave sensors, since the optical portion provided information concerning vegetation type, density and moisture content, while the microwave portion furnished information on surface roughness and texture. The overall objective of this study is to determine if there are synergistic effects when digital space borne ERS-2 SAR data combined with IRS-1D LISS-III data. The hypothesis is that the combined data set from optical and microwave sensors would improve the interpretation capability of coastal wetland features compared to utilizing data from either radar or optical data (Ramsey *et al.*, 1998). In the present study, five fusion models attempted for data integration

are Multiplicative Transform (MT), Principal Component Transform (PCT), Intensity-Hue-Saturation (IHS), Brovey Transform (BT) and Wavelet Transform (WT). The image data sets were subjected to each of the five data fusion techniques. More details concerning fusion techniques can be found in a referee (Shanmugam, 2002). The results of these techniques were analyzed in order to evaluate their spectral integrity and image-interpretive potential for better information extraction about coastal wetland features.

## 6. Results and Discussions

The comparative performances of several speckle suppression algorithms and integration techniques were investigated based on visual and statistical procedures to assess the potential use of combining optical and microwave image data for mapping the complex coastal wetland features of southern India. Since, the SAR image makes difficult in differentiating number of grey levels by human perception, the comparative analysis of speckle filters was studied on the microwave (SAR) data alone and on the combined multispectral + SAR data (using brovey transform) for better evaluation (Fig. 4).

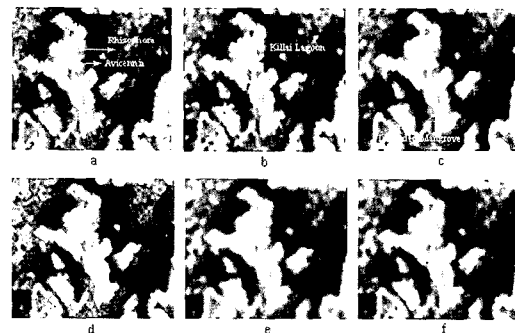


Fig. 4. Results of speckle filters showing a part of the Pitchavaram study site: (a) Local region filtered SAR+LISS-III (b) Frost filtered SAR+LISS-III (c) Median filtered SAR+LISS-III, (d) Lee filtered SAR+LISS-III, (e) Gamma filtered SAR+LISS-III, and (f) Leesigma filtered SAR+LISS-III.

Visual analysis reveals that significant improvement was achieved by all filtering algorithms in terms of enhancing mangrove communities in the fused images. It is, however, that the local region filter ( $3 \times 3$ ) yields good information about the two mangrove communities (*Rhizophora apiculata* and *Avicennia marina*) in preserving boundaries, textures and in smoothening homogeneous areas of mangroves (Fig. 4a). The frost and median filters ( $3 \times 3$ ) are slightly less superior to local region filter in smoothening homogeneous areas of mangrove communities and conserving their textures

(Figs. 4b&c). Lee filter ( $5 \times 5$ ) seems effective in smoothening homogeneous areas of mangrove communities, but is not as effective in conserving boundaries and textures (Fig. 4d). Gamma and leesigma filters ( $3 \times 3$ ) show adaptivity as well but the textures and boundaries of the mangroves are partially blurred (Figs. 4e and 4f). The investigation was also carried out on different wetland features by increasing window size but these features were not clear and highly degraded with increasing window size. The general statistics of the original, filtered and combined images (SAR+LISS-

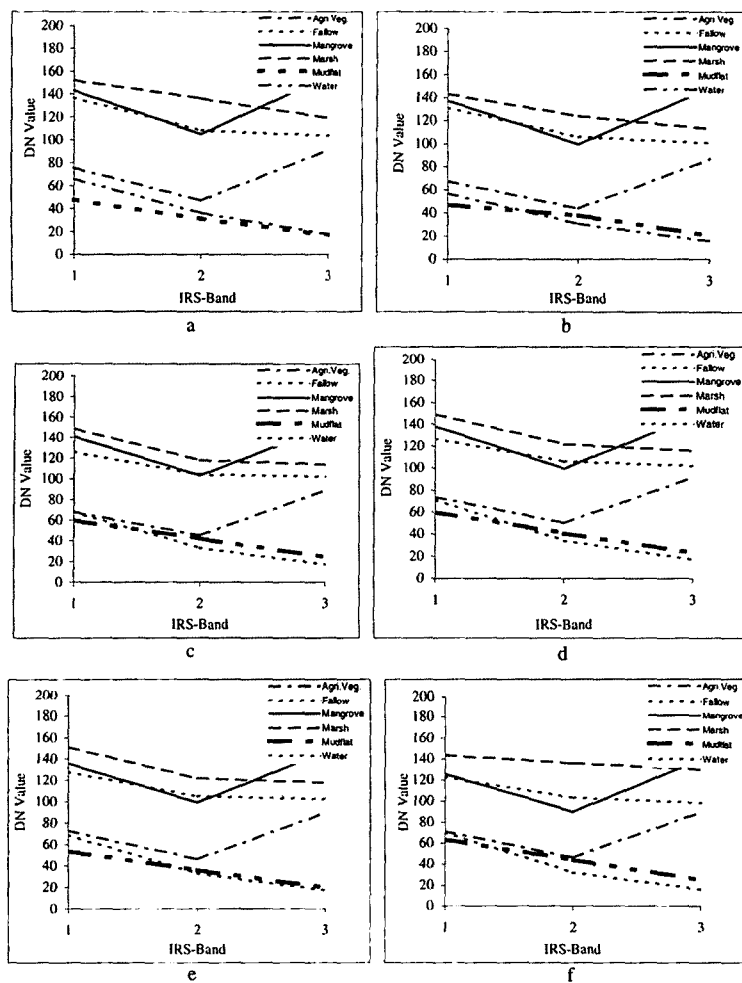


Fig. 5. Mean spectral signatures (TD) of five cover types derived from combined SAR and LISS-III images of the Local region filter (a), Frost filter (b), Lee filter (c), Gamma filter (d), Median filter (e), and Leesigma filter (f).

III) are reported in Table. 1. From this table, it is inferred that the local region algorithm seems to suppress the noise content in the filtered image and is found to preserve spectral content of the combined image. The filtered frost and leesigma images appear to preserve speckle as of original SAR image while yielding less spectral values in the combined images. Similarly, gamma and median filters are not capable in suppressing

speckle as well compared to local region filter while there is considerable spectral distortion observed in lee filtered image.

The comparative performance of various speckle suppression algorithms applied on radar images was also investigated using separability analysis in the view of classification. In this study, Transformed Divergence (TD) that is a measure of separability is used to

Table. 1. General statistics of the original and processed images of the study site.

Original, filtered and combined Images	Layers	Mean	Std.D
IRS-1D LISS-III image	1	117.5	17.5
	2	75.5	16.9
	3	85.1	23.6
ERS-2 SAR image	1	190.2	60.8
Local region filtered SAR image	1	188.2	55.8
Frost filtered SAR image	1	189.5	53.3
Gamma filtered SAR image	1	188.8	48.2
Lee filtered SAR image	1	187.5	51.3
Lee-sigma SAR filtered image	1	189.6	48.6
Median filtered SAR image	1	188.3	49.2
Local region filtered SAR+LISS-III	1	99.2	53.2
	2	74.3	48.4
	3	88.3	54.8
Frost filtered SAR+LISS-III	1	98.8	51.3
	2	73	47.3
	3	86	54.3
Gamma filtered SAR+LISS-III	1	97.3	49.3
	2	71.5	45.6
	3	84.2	53.5
Lee filtered SAR+LISS-III	1	98.2	51.2
	2	72.7	47.1
	3	85.5	54.3
Lee-sigma filtered SAR+LISS-III	1	97	48.3
	2	70.6	44.7
	3	83.1	53
Median filter (SAR+LISS-III)	1	98.1	50.5
	2	72.3	46.7
	3	85.7	54.1

determine whether the signatures are separable. TD values have an upper (2000) and a lower bound (0). If the calculated divergence is equal to the upper bound, then the signatures can be said to be totally separable in the bands being analyzed. A calculated divergence of zero means that the signatures are inseparable. Transformed Divergence (TD) was used over the bands 1, 2, and 3 of the combined SAR and LISS-III images. Six coastal landcover features, namely marsh, mangrove, mudflat, water, agricultural vegetation and fallow land were selected for the analysis (Fig. 5). Transformed Divergence was computed for each of the six classes. It was observed that the classes derived from the combined image of local region filter yielded highest separability among the classes compared to other filters. The mean spectral values obtained from the combined

image of local region for mangroves, marsh and agricultural vegetation are always found to be higher than the mean spectral values of the images of other filters (Fig. 5a). Similarly, frost filter provided moderate separability for vegetation classes but it yielded poor separability for mudflat and water classes. The classes derived from Lee and Gamma filtered images (combined image) were moderately separable. In contrast, Leesigma filter yielded good separability in mudflat and water classes while poor separability was found in other classes by using this filter. Based on visual, statistical and separability analysis, it was strongly confirmed that the local region filter performed well in preserving boundaries, textures, and smoothening homogeneous regions, and yielding good separability among the classes.

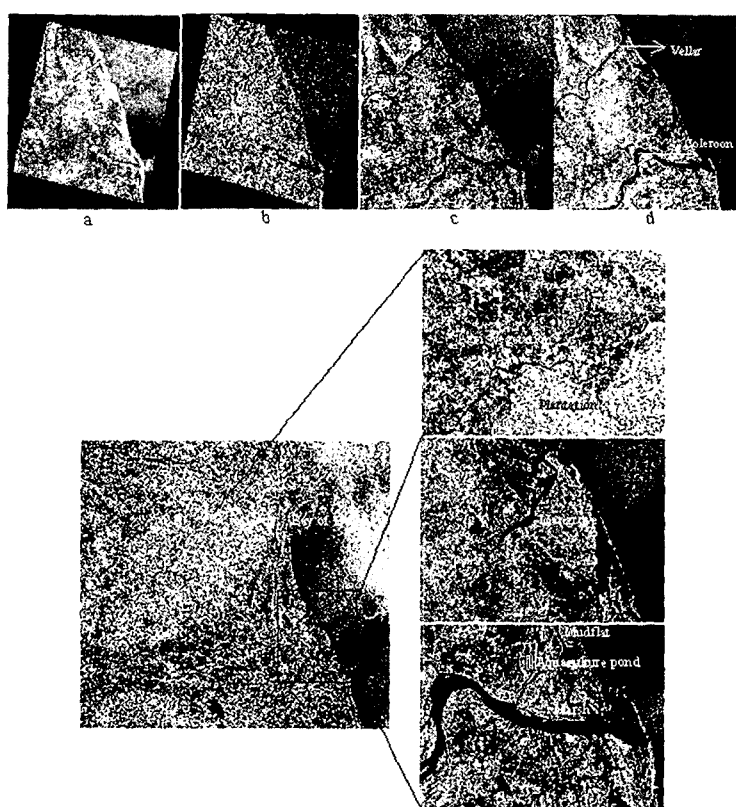


Fig. 6. Results of fusion of IRS-1D LISS-III (band 321) and ERS-2 SAR images of Pitchavaram study site: (a) PCT image, (b) WT image, (c) IHS image, (d) MT image, and (e) BT image.



Based on the detailed analysis of speckle filtering algorithms, the local region filter was found to be more appropriate for further analysis of integration. Thus local region filtered SAR data was subjected to integration with LISS-III data using above fusion techniques. The combination of LISS-III + SAR data produced enhanced images. The visual comparison shows that a significant improvement in discriminating mangrove communities and other wetland features was achieved in fused images compared to either of a single data alone. As shown in Fig. 4, the mangrove communities (*Rhizophora apiculata*- red tone, *Avicennia marina*- light red tone) are well discriminated in the fused images compared to the LISS-III image (Fig. 1a). In Pitchavaram study site, it can be observed that largely *Rhizophora apiculata* species located on the margin of lagoon waters are of relatively low density, with extensive above root systems contributing to a large proportion of the biomass (Fig. 1c). In contrast, *Avicennia marina* just away from the water has lower overall biomass than *Rhizophora apiculata* but the tree density is much greater than *Rhizophora apiculata*. This is evident in all fused images. The change in tonal variation as seen in Fig. 4a is mainly due to differing in radar backscatter where the high backscatter from *Rhizophora apiculata* appears as dark red tone while low backscatter from *Avicennia marina* appears to be light red. As the C-band of ERS-2 SAR is highly sensitive to crown characteristics (number, density, size and orientation of leaves) and structure (architecture and heterogeneity), it results in high backscatter at co-polarization to increasing biomass of *Rhizophora apiculata* rather than *Avicennia marina*.

It can be observed that among all techniques used in this study, the brovey transform appears to be more effective in enhancing mangrove communities, mudflat, aquaculture, scrub, plantation, agricultural area and fallow land while reducing cloud cover significantly compared to other models (Fig. 6). PCT highlights

vegetation communities while IHS technique has good potential in enhancing the mangroves, scrub, mudflat, plantation, agricultural vegetation and lagoon but it yields less information about aquaculture, fallow, sandy area. Multiplicative transform distorts overall information and the features are highly blurred in the fused image. In contrast, the wavelet transform does not show any visual interpretability as can be seen in Fig. 6b. Similarly, the statistical analysis of original and fused images (made on subset images) shows that the brovey transform yields satisfactory result in preserving spectral content of the original image data while others tend to distort the spectral integrity of LISS-III image data (Table. 2). Although the Wavelet fused image is quite satisfactory in preserving spectral content, the visual interpretability of this image is poor compared to other techniques. The PCT overestimates the statistics of original image data while IHS transform underestimates the original spectral values. The multiplicative transform yields poor spectral information of the original image. The results of the above procedure showed that the combined use of different characteristics of the image data by fusion techniques improved the visual and digital interpretability of different mangrove communities and other wetland features of the study site.

## 7. Conclusions

Optical (IRS-1D LISS-III) and microwave (ERS-2 SAR) data are complementary to coastal information extraction and they provided excellent information about different mangrove communities, degraded mangroves, aquaculture ponds, dry and wet mudflat, reclaimed mudflat, marsh and associated lagoonal system in the study site. No previous study discriminated *Rhizophora apiculata* and *Avicennia marina* from the remotely sensed data. The fact is that these features are not clearly seen in the original LISS-III image or LISS-III and PAN

Table. 2. General statistics of the original and fused images of the Pitchavaram study site.

Original and fused images	Layers	Minimum	Maximum	Mean	SD
ERS-2 SAR image	1	25	964	212.6	81.6
Filtered SAR image (LRF*)	1	29	782	210.8	77.3
IRS-1D LISS-III image	1	45	255	81	21.8
	2	21	239	54	23.6
	3	12	217	76	39.7
Brovey image	1	4	255	71.5	38.8
	2	8	227	53.6	21.5
	3	14	255	85	35.3
IHS image	1	1	38	7.5	4
	2	103	116	105.5	1.3
	3	1	27	7.7	3.4
PCT image	1	25	138	56.3	11.3
	2	24	165	62.2	12
	3	10	106	73.5	7.7
Multiplicative image	1	2	31	7.6	2.7
	2	2	31	6.8	3.1
	3	1	65	9.8	5.8
Wavelet image	1	1	228	92.4	43
	2	1	188	71.2	37
	3	1	220	91.4	41.7

\*Local region filter, SD- Standard deviation

fused image (Shanmugam, 2002). But, the distribution of these communities can be identified and mapped when fusing optical and C-band (low penetration) synthetic aperture radar data as demonstrated in the previous sections. Based on the visual and statistical analysis, it was observed that the brovey transform appeared to be good potential of preserving spatial and spectral information of the original image data. This was followed by PCT and IHS transforms that enhanced vegetation communities within the study region, but distorted spectral details to the extent. In contrast, the spatial details were highly degraded in using wavelet transform and it failed to operate well for cloudy regions. This is due to the fact that the high values in the

LISS-III bands were eventually preserved in the fused image of wavelet transform. On the other hand, the visual and statistical analyses clearly indicated the necessity of performing speckle-filtering algorithms to remove the speckle noise from the radar image data. The performance of local region filter was found to be superior among all filters adopted in the present study. From this study, we conclude with the potential use of filtering algorithms and the complementary data sets for more accurate mapping of highly fragile coastal mangrove wetland ecosystem. The future work will focus on the use of different SAR systems (with multi-band and multi-polarizations) for improved understanding of the coastal zone wetland systems.

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