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Potential of Envisat ASAR data for woody biomass assessment

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Abstract: This study explores the potential of Envisat ASAR data for biomass estimation in Dudhwa National Park of Lakhimpur-Kheri district in Uttar Pradesh state of India. The DNP has sal forest, forest plantations, grasslands, croplands, settlements, wetlands and the water bodies. Various window sizes and filters were tried to minimize the speckles in ASAR data and a 7 x 7 pixel window and Gamma-MAP filter combination was found to be most suitable. Different combinations of un-filtered, filtered, and texture images were used for forest/land cover classification followed by mapping accuracy assessment. The mapping accuracy was lowest with raw data. Filtering and texture transformation increased the accuracy marginally. The correlation coefficient (R^2) between the backscatter and biomass was noticed to be better for low biomass (R^2=0.86) than high biomass (R^2=0.01). In general, the HV polarization showed better relationship than HH polarization.

Resumen: Este estudio explora el potencial de los datos del Envisat ASAR para la estimación de la biomasa en el Parque Nacional Dudhwa del distrito Lakhimpur-Kheri, estado Uttar Pradesh, India. El Parque tiene bosque de sal, plantaciones forestales, pastizales, tierras de cultivo, asentamientos humanos, humedales y cuerpos de agua. Se probaron ventanas de varios tamaños y diferentes filtros con el fin de minimizar las manchas en los datos ASAR y se encontró que la combinación de una ventana de 7 × 7 pixeles con filtro Gamma-MAP era la más adecuada. Se usaron diferentes combinaciones de imágenes no filtradas, filtradas y de textura para la clasificación del bosque y la cobertura de suelo, seguida por una evaluación de la exactitud en la cartografía. La exactitud de la cartografía fue mínima con los datos crudos. El filtrado y la transformación de la textura incrementaron la exactitud de forma marginal. El coeficiente de correlación (R^2) entre el reflejo del fondo (backscatter) y la biomasa fue mejor para los valores bajos de biomasa (R^2=0.86) que para los altos (R^2=0.01). En general, la polarización HV mostró una mejor relación que la polarización HH.

Resumo: Este estudo explora o potencial dos dados do Envisat ASAR para a avaliação da biomassa no Parque Nacional de Dudhwa (DNP) do distrito de Lakhimpur-Kheri no Estado de Uttar Pradesh na Índia. O DNP tem floresta de meranti, plantações florestais, pastagens, culturas, zonas de povoamento humano, zonas alagadas e cursos de água. Para minimizar os picos de dados do ASAR verificou-se que a combinação de uma janela de 7x7 pixels e filtro Gamma-MAP foi a mais favorável. Foram usadas diferentes combinações de dados não filtrados, filtrados e de textura das imagens para a classificação do coberto floresta/terra seguida da avaliação da sua exactidão. A exactidão do mapeamento foi mais baixa com dados crus. A filtragem e a transformação da textura aumentaram a exactidão marginalmente. Observou-se que o coeficiente de correlação (R^2) entre a reflexão de fundo e a biomassa foi melhor para biomassas baixas (R^2=0.86) do que para os valores altos de biomassa (R^2=0.01). No geral, a polarização de HV mostrou uma melhor correlação do que a polarização de HH.

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Key words: ASAR, biomass, Envisat, forest, polarization, speckle, texture.

Introduction

Forests are the important resources, which provide a wide range of goods and services in addition to their role in maintaining the ecological balance (Berlyn & Ashton 1996). The forest ecosystems can be optimally managed if timely information on their structure and function is available. The advent of remote sensing has provided unprecedented opportunities for forest resources assessment, monitoring and management. The major problem associated with optical remote sensing data is the presence of clouds, fog and snow. The tropical forests are covered by the clouds for considerable periods of time yearly, especially during growing periods, making mapping/monitoring using optical data a difficult task. Optical remote sensing data has been successfully used in the past for herbaceous biomass estimation because spectral reflectance of such vegetation is positively correlated with the leaf area index (LAI). The LAI, in turn, is positively correlated with the herbaceous biomass (Tucker & Sellers 1986). The forest stand volume and woody biomass, however, are poorly correlated with spectral reflectance. Hence, utility of optical remote sensing data for forest stand volume or biomass estimation is very limited. The active microwave sensors like synthetic aperture radar (SAR) by virtue of their capability to penetrate the clouds, fog or haze, provide data during any hour of the day or night (Krohn *et al.* 1983). The continuous data gathering capability of SAR has opened new vistas in forest resources management in the regions of the world with perpetual cloud cover problems (Imhoff & Story 1986; Sanden 1997). In addition to this, the microwave data can provide information on the forest structure, which is helpful in stand volume and biomass assessment (Kimball *et al.* 2004a, 2004b; Frolking *et al.* 2005).

The radar backscattering is basically affected by surface roughness and the dielectric properties of the features (Blanchard & Chang 1983). The analysis of radar data acquired using different wavelengths and polarimetry has shown sensitivity to vegetation cover and biomass as short wavelengths do not penetrate the canopy. Radar X- and C-bands have been found to be useful for canopy cover assessment (Dwivedi *et al.* 2000; Hoekman *et al.* 2001; Kushwaha *et al.* 2000). The long wavelength L- and P-bands, on the other hand, are able to penetrate the canopy and reach to branches and trunks. Trunks are usually modeled as dielectric cylinders with smooth surfaces. Because of this property of the tree trunks, the backscattering from this stratum is dependent on the tree-ground double bounce, which then could be correlated with stand volume and biomass (as product of volume and specific gravity of wood). Champion *et al.* (2008) studied radar image texture as a function of forest stand age. Chand & Badrinath (2007) found good relationship between C-band backscatter and the deciduous forest parameters. Many studies have indicated that the C-band forest backscatter may saturate at an aboveground biomass of 30-50 t/ha. While the saturation point may vary from forest to forest, the factors such as SAR viewing geometry are also important (Foody *et al.* 1997). Good correlation has been observed between the woody biomass and relative backscattering coefficient using L/P-bands (Fransson 1999; Rauste 2005). Using JPL-AIRSAR data, Kellndorfer *et al.* (2003) found significant relationships between stem density, dominant height, basal area and backscatter of pine forest. Kuplich *et al.* (2000) found an R^2 value of 0.77 in a study on the relationship of backscatter with biomass of a regenerating forest.

Luckman *et al.* (2000) noticed a R^2 value of 0.80 between ERS-1/2 tandem coherence and the log of forest biomass for a regenerating tropical forest. Fransson *et al.* (2001) observed the correlation coefficients of 0.46 to 0.87 between coherence and stem volume. Pulliainen *et al.* (2003) observed that weather affects repeat-pass interferometry. Recent study by Champion *et al.* (2008) has related stand volume, biomass, density etc. to additional SAR characteristics *viz.*, texture, coherence, interferogram and the polarimetry. The present study was undertaken to test the utility of Envisat ASAR C-band data for forest biomass assessment.

Materials and methods

Study site

Dudhwa National Park (DNP) (28° 18′ - 28° 42′ N and 80° 28′ - 80° 57′ E) falling in the terai region of Uttar Pradesh bordering Nepal was selected for this study (Fig. 1). Total park area is about 684 km^2. The park is a vast alluvial plain sandwiched between Mohana and Suheli rivers. The rich and highly fertile soils support a luxuriant growth of forests with high plant and animal diversity. As per the classification of Champian & Seth (1968) four major forest types occur in DNP. The eleven forest types have been reported from DNP in the tiger status report of the MoEF (2001). Sal (*Shorea robusta* Gaertn.) Forests dominate the landscape. Other prominent forest/vegetation types are: Semi-Evergreen Forest, Moist Deciduous Forest, Sain (*Terminalia tomentosa* Wight & Arn.) Forest, Khair-Shisham (*Acacia catechu* Willd.- *Dalbergia sissoo* Roxb.) Forest, Jamun (*Syzigium cumini* L.) Forest and Grasslands. Besides, there are several areas with teak (*Tectona grandis* L.f.), eucalyptus (*Eucalyptus hybrid*), shisham, khair and asidha (*Lagerstroemia parviflora* Roxb.) plantations. This makes DNP an ideal area to test the potential of radar data for forest cover, stand volume and biomass assessment.

Data used

The Envisat ASAR IS-3 beam (25.8°-31.2°) HH and HV polarization data of 24th March, 2005 with a swath width of 82 km was procured through National Remote Sensing Centre, Hyderabad and used in this study. Ancillary data like topographic and forest management maps were also used. Fig. 2 shows the Envisat ASAR false colour composite (FCC).

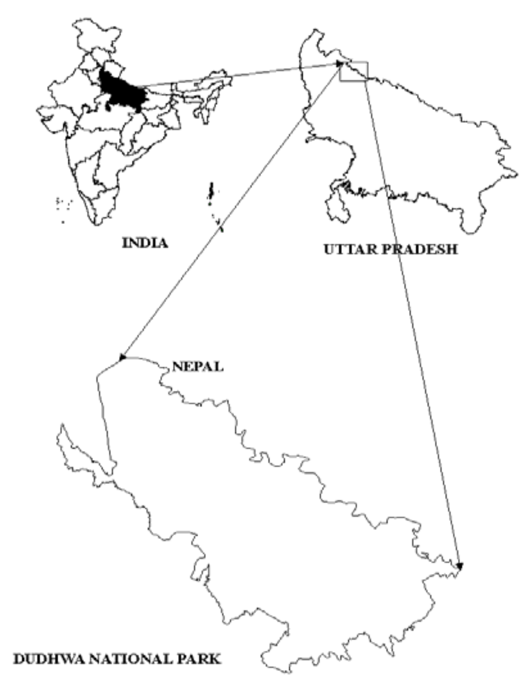

Fig. 1. Location of Dudhwa National Park in India

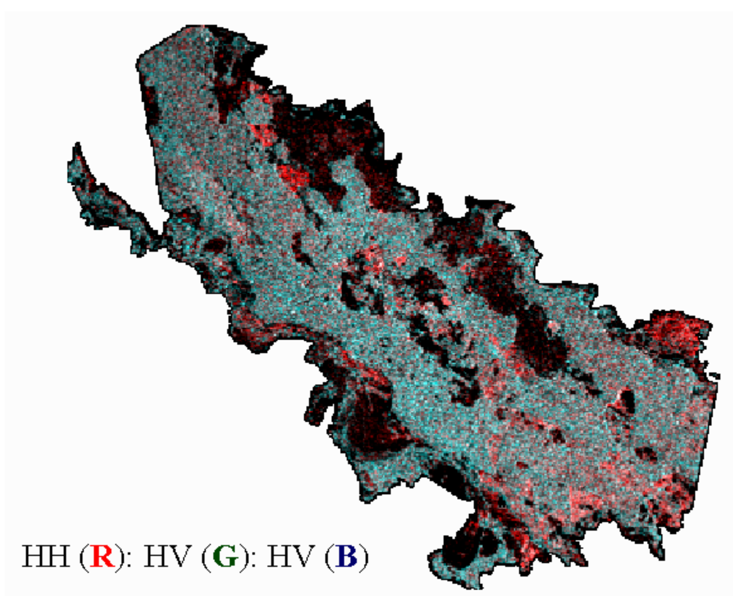

Fig. 2. Envisat ASAR FCC for the study area.

Table 1. Effect of various filters used on HV data.

Filter	Raw		Gamma		Mean		Median		Lee-Sigma		Lee		Frost	
Feature	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Grassland	184.36	47.04	185.04	9.66	186.33	9.53	190.52	14.61	180.81	18.65	146.88	26.28	111.76	11.94
Wetland	80.30	23.88	78.22	4.03	76.60	6.76	78.06	6.63	75.00	8.21	65.00	12.30	80.36	14.24
Mixed forest	164.14	35.86	187.59	11.64	188.94	11.84	194.48	17.13	182.98	19.08	150.01	24.85	187.73	24.89
Plantation	206.82	47.25	210.40	10.31	205.42	12.13	211.14	18.46	200.49	16.97	165.43	24.22	207.83	22.26
Sal forest	227.14	35.95	223.16	7.03	225.42	7.43	241.17	15.67	225.08	8.06	180.23	19.84	226.22	9.29

Table 2. Effect of various filters used on HH data.

Filter	Raw		Gamma		Mean		Median		Lee-Sigma		Lee		Frost	
Feature	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Grassland	250.97	14.51	246.93	3.88	250.03	3.30	255.00	0.00	250.03	3.30	197.79	13.90	250.28	2.84
Wetland	123.82	45.29	115.24	9.64	74.25	9.15	111.80	13.46	107.48	16.86	101.42	25.75	121.76	34.96
Mixed forest	240.52	27.60	238.98	7.85	241.42	7.35	251.51	7.56	239.90	11.88	189.70	20.57	240.08	12.08
Plantation	252.27	8.61	250.63	2.24	252.37	1.69	254.64	0.35	252.37	1.69	198.54	14.55	252.32	2.95
Sal forest	252.03	11.66	250.41	3.56	252.34	2.45	255.00	0.00	252.34	2.45	198.42	14.85	252.26	2.63

Data processing and forest cover mapping

A field visit to DNP was made for ground truth collection. All forest/land cover types were visited and geo-coordinates of ground truth points were marked using a Magellan global positioning system (GPS) receiver. The Envisat ASAR image was geo-rectified using ground control points collected during field work, second order polynomials and the nearest neighbour resampling with a Root Mean Square Error (RMSE) of less than one pixel. The speckle of ASAR data was minimized using appropriate filters. A texture image was generated since textural information in radar images may be as important as spectral information. The FCC generated from filtered, un-filtered and the texture images, was rendered to supervised and unsupervised classifications to generate the forest/land cover type map. The mapping accuracy was verified on ground during next field visit.

Biomass assessment

The stratum size was effectively utilized for determining the number of field inventory plots using stratified random sampling design. A total of 191 plots of 20 m x 20 m size were laid in different forests. During two later visits, forest inventory data on tree height and diameter at breast height was collected. The field inventory data was used for volume/growing stock estimation using species-specific volume equations developed by Forest Survey of India, Dehradun (FSI 1996). The wood volume was multiplied by specific gravity to arrive at the biomass. The growing stock-based approach for aboveground biomass estimation has been used widely and is considered superior to remote sensing-based method (Chhabra *et al.* 2002). The radar backscattering coefficient, σ^o was extracted from the SAR data using a 7x7 pixel window and correlated with the woody biomass of the study site. Fig. 3 illustrates the paradigm of the study.

Table 3. Relationship between HH-HV combined polarization and the filter output.

Filter	Linear Regression	R^2
Gamma-Map	Y = -1.51x+0.25	0.58
Mean	Y = 1.00x	1.00
Median	Y = 1.56x-0.18	0.98
Lee-Sigma	Y = 1.47x-0.49	0.94
Lee	Y = 1.56x-0.17	0.98
Frost	Y = -1.51x-0.09	0.97

Table 4. Producer's and user's accuracies (%) of HH-HV image classification.

Forest/Land Cover	Producer's Accuracy	User's Accuracy
Sal forest	60.72	81.79
Agriculture	31.56	74.28
Teak plantation	45.95	33.71
Teak mixed forest	54.50	22.94
Wetland	92.96	98.28
River	91.36	25.64
Mixed forest	4.43	19.35
Grassland	7.40	24.39
Eucalyptus plantation	55.71	4.75
Shisham	33.99	2.04

Results and discussion

The ASAR images were speckle-filtered using six different filters *viz.*, namely Gamma - Map, Mean, Median, Lee-Sigma, Lee and Frost. These filters were evaluated for their efficiency to reduce speckle based on the premise that the filter that retains the mean of the DN values of the raw data while reduces the standard deviation to the minimum, is the most efficient (Wakabayashi & Arai 1996). Median filter yielded best results for

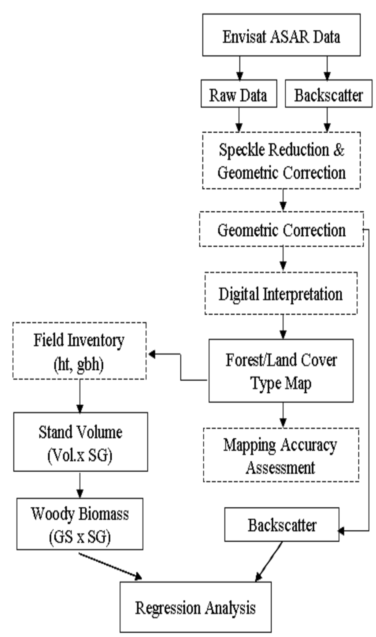

Fig. 3. Paradigm of the study.

HH polarization and Gamma-Map filter produced best results for HV polarization. Images generated using Median (HH polarization) and Gamma-Map filters (HV polarization) were used subsequently for further analysis (Tables 1, 2 & 3). The major vegetation types that could be mapped from ASAR data were sal forest, mixed forest, teak plantation, teak mixed plantation, shisham plantation, eucalyptus plantation, grassland, agriculture, river and wetland. Fig. 4 shows the classified and color-coded image depicting different forest/land cover types. The overall accuracy of classification worked out to be 41%, which is very low compared to the classification accuracy (92%, Kushwaha *et al*. 2007) achieved using Landsat ETM+ data for the same area. The class-wise accuracy was good for sal forest, *Eucalyptus* plantation, wetland and the water body, while it was highest for wetland (Table 4).

The results revealed that majority of the forests in the study area have high biomass. The average woody biomass ranged from 62.01 t/ha (shisham plantation) to 305.62 t/ha (sal). Sal forest had highest biomass. The field estimated biomass was correlated with the backscatter to examine the relationship between the backscattering and the biomass and a correlation coefficient of 0.002 and

Table 5. Relationship of HH and HV backscatter with the biomass.

Forest Type	N	Range (t/ha)	Polarization	Model	R^2
Sal forest	92	116-520	HH	y = 8.152x + 381.4	0.01
			HV	y = 11.65x + 467.9	0.02
Sal mixed forest	8	230-519	HH	y = 45.525x + 836.01	0.07
			HV	y = -40.314x – 151.97	0.14
Mixed forest	30	45-228	HH	y = -3.191x + 70.307	0.02
			HV	y = -5.9337x + 14.499	0.05
Jamun forest	6	47-168	HH	y = 37.416x + 480.81	0.53
			HV	y = 51.244x + 886.44	0.49
Khair-shisham Forest	3	84-250	HH	y= 14.593x + 308.46	0.11
			HV	y = -57.801x – 826.36	0.86*
Teak Plantation	30	63-410	HH	y = -20.62x - 12.71	0.13
			HV	y = 25.27x + 542.7	0.23
Eucaluptus plantation	10	4-162	HH	y = -13.114x – 44.768	0.11
			HV	y = 32.857x + 634.76	0.68*
Shisham Plantation	12	15-114	HH	y = -9.787x – 37.47	0.70*
			HV	y = 7.139x + 173.5	0.06
All	191	4-520	HH	y = -4.638x + 173.3	0.002
			HV	y = 37.85x + 769.2	0.20

* Significance at 35% confidence level

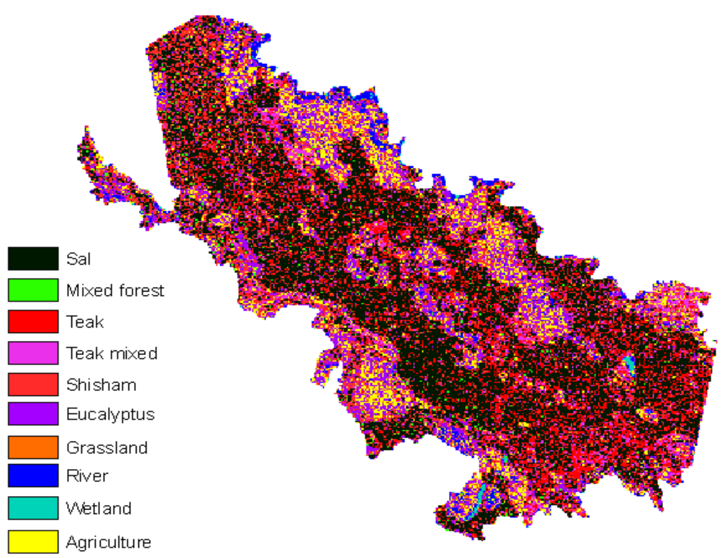

Fig. 4. Classified image depicting forest/land cover types.

0.20 was noticed in case of HH and HV polarizations, respectively. The correlation coefficient ranged from 0.01 (sal forest) to 0.70 (shisham plantation) in case of HH and from 0.02 (sal forest) to 0.86 (khair-shisham) in case of HV polarization. The biomass in majority of the DNP forests exceeded the typically quoted saturation values. In general, the relationship was observed to be poor in both HV and HH polarizations in case of high biomass forests. The HV backscatter, in general, showed better relationship than HH backscatter (Table 5). As evident from the above results, the ASAR data did not show significant correlation with high biomass of the study site thus, indicating limited utility of the ASAR data for biomass assessment. The results this preliminary study conform the findings of other similar studies carried out using C-band data (Rauste 1993; Rauste *et al.* 1994; Harrell *et al.* 1995; Harrell *et al.* 1997).

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