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Remote sensing to map the invasive weed, *Lantana camara* in forests

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Abstract: The present study evaluates the utility of Indian Remote Sensing Satellite data for detection, mapping and patch information extraction of the invasive weed, *Lantana camara*. The test site was a part of the Rajaji National Park forest in Uttarakhand. The major natural vegetation type present in the area is sal (*Shorea robusta*) forest. *L. camara* grows profusely in degraded and sparse forests in the park. The IRS LISS-IV and LISS-IV plus Cartosat-1 merged data were used to test their suitability for differentiation of *Lantana* from the surrounding vegetation with digital classification. The merged product facilitated maximum differentiation (96.4%) followed by LISS-IV (92.9%). Cartosat-1 (alone) resulted in poor accuracy (65%). A similar trend among data sets was seen in the identification of the number and size of *Lantana* patches. The study demonstrated the high potential of LISS-IV and Cartosat-1 merged data for differentiation and mapping of *L. camara*.

Resumen: El presente estudio evalúa la utilidad de los datos del Satélite Indio de Percepción Remota para la detección, cartografía y extracción de información de los parches de la especie invasora *Lantana camara*. El sitio de prueba fue una porción del bosque en el Parque Nacional Rajaji, en Uttarakhand. El principal tipo de vegetación natural presente en el área es el bosque de sal *(Shorea robusta)*. *L. camara* crece profusamente en los bosques degradados y dispersos en el parque. Los datos del IRS LISS-IV y del LISS-IV, más los datos combinados del Cartosat-1, fueron probados para determinar si eran adecuados para diferenciar a *Lantana* de la vegetación circundante con la clasificación digital. El producto combinado hizo posible la diferenciación máxima (96.4%), seguido por LISS-IV (92.9%). Cartosat-1 (por sí solo) resultó en una exactitud baja (65%). Se observó una tendencia similar entre los conjuntos de datos en la identificación del número y tamaño de los parches de Lantana. El estudio demostró el potencial alto de los datos combinados LISS-IV y Cartosat-1 para la diferenciación y la cartografía de *L. camara*.

Resumo: O estudo actual avalia a utilidade dos dados do Satélite Indiano de Detecção Remota para a detecção, mapeamento e a extracção da informação parcelar sobre a invasão da *Lantana camara*. O local de teste foi uma parte da floresta do Parque Nacional de Rajaji em Uttarakhand. O principal tipo de vegetação natural actual na área é a floresta de meranti *(Shorea robusta)*. A *L. camara* cresce profusamente em florestas degradadas e pouco densas no parque. Os dados agregados dos IRS LISS-IV, LISS-IV e do Cartosat-1 foram usados para testar a sua viabilidade para a diferenciação da *Lantana* com classificação digital em relação à vegetação circundante. O produto agregado facilitou a diferenciação máxima (96.4%) seguida por LISS-IV (92.9%). O uso isolado do Cartosat-1 resultou numa exactidão pobre (65%). Uma tendência similar entre séries de dados foi encontrada na identificação do número e do tamanho das manchas de *Lantana*. O estudo demonstrou o elevado potencial da fusão de dados do LISS-IV e Cartosat-1 para a diferenciação e mapeamento da L. camara.

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Key words: Cartosat-1, image fusion, invasive, *Lantana*, LISS-IV, texture.

Introduction

The rapid colonization and spread of invasive species is recognized as a primary cause of global biodiversity depletion (Wilcove & Chen 1998). Invasive alien species (IAS) are the species, sub-species or lower taxon occurring outside of their natural range and dispersal potential and includes any part of such species that might survive and subsequently reproduce (Turlings 2000). The process of invasion of non-native species has occurred in three phases namely arrival, establishment and spread. Terrestrial exotic species like *Cytisus scoparius* L., *Chromolaena odorata* (L.) King & H.Rob., *Eupatorium adenophorum* (Spreng.) King & H. Rob., *Lantana camara* L., *Mikania micrantha* Kunth, *Mimosa invisa* C. Wright, *Parthenium hysterophorus* L. and *Prosopis juliflora* Stuntz DC. and aquatic exotics like *Eichhornia crassipes* (Mart.) Solms and *Pistia stratiotes* L. are posing serious threat to the native flora of India.

During the past few decades, India has witnessed negative impact on forest ecosystems posed by invasive species. Among them, the *Lantana camara* (Verbeinaceae) is one of the most serious invasive plant species and has colonized large areas of forest in the Himalayan foothills (Shiwalik range), particularly the Dudhwa, Corbett and Rajaji National Parks. It has also invaded the wastelands and forest areas of Western Ghats and other ecosystems especially in peninsular and northeast India (Murali & Setty 2001). In some of the areas of the parks, *Lantana* growth has completely replaced original native forests and palatable grasses, the main food of several species of herbivorous animals (Joshi 2002). As a result, the food chain and movements of wildlife has been disturbed drastically (Joshi 2002). Rawat & Bhainsora (1999) recorded the highest average density of *Lantana* bushes (i.e. 18 per 100 m^2) in Doon valley followed by Shiwaliks (9.2 per 100 m^2) and the outer Himalayas (7 per 100 m^2). Joshi (2002) reported *Lantana* distribution from 400 m to 1400 m above m.s.l. There is an urgent need to control this weed to save native biodiversity. The information on the extent and distribution of *Lantana* is important to control the species.

High resolution remote sensing data has received considerable attention for inventory of invasive species. The multi-date satellite imagery facilitates monitoring phenological changes and thus, species identification. Integration of satellite-derived information with other attributes in GIS can be useful in predicting the spread of the invasive species. Remote sensing of invasive plants has only been successful when the invasive is in an aquatic, wetland, riparian, grassland or desert environment, where the absence of tree cover gives the sensors an unobstructed view of the invasive plant (Bradley & Mustard 2006). Thus, under story invasives pose a challenge. Hyperspectral data have been used by many researchers for detection and mapping of invasive species (Lawrence *et al*. 2004). A particular advantage of using hyperspectral imagery for invasive species mapping is its potential to determine the relative components, or unmixed pixels, which can be especially valuable for determining the percent cover of species including sub-pixel infestations (Glenn *et al*. 2005). The present study evaluates the utility of different Indian remote sensing data for detection, mapping, and patch information extraction of *L. camara* with emphasis on the automatic information extraction techniques. The test site selected was part of the Rajaji National Park in Shiwaliks. The major objectives of the study were: (i) to establish a phenological trend for the extraction from temporal satellite data of understory invasive plants (i.e. *Lantana camara*), (ii) to evaluate the utility of different Indian remote sensing sensors for detection, mapping and patch-size estimation of *Lantana,* and (iii) to develop techniques to identify *L. camara* patches using high resolution multispectral and texture information.

Material and methods

Study area

The area chosen for this study was a small part of the Rajaji National Park (Fig.1) lying between 30° 08' - 30° 10' N latitude and 77° 52' - 77° 57' E longitude. The terrain is rugged, broken and highly undulating until it reaches the bhabhar tract. The altitude ranges from 302 to 1000 m above m.s.l. The climate is moist to dry sub-

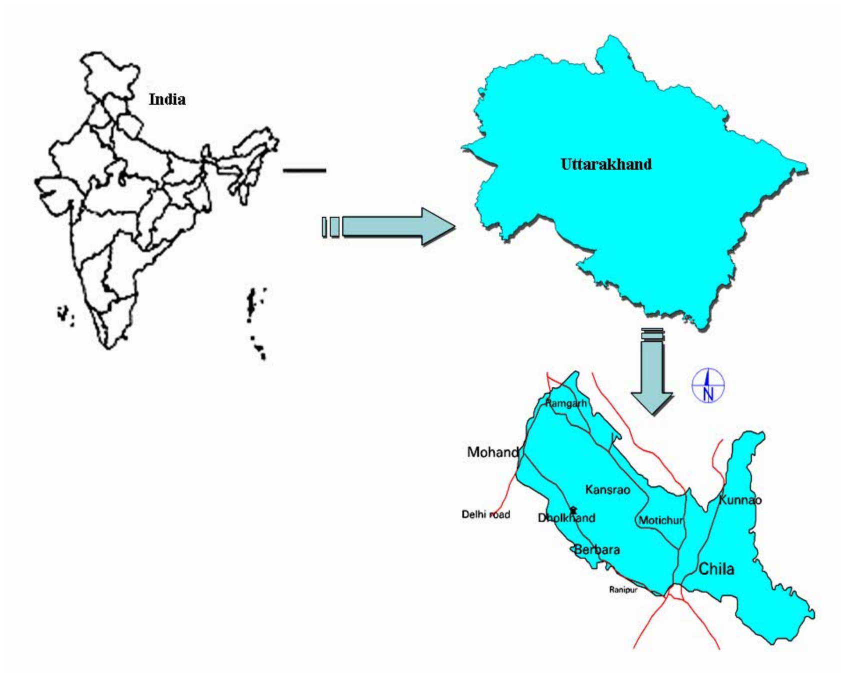

Fig. 1. The location of the study area.

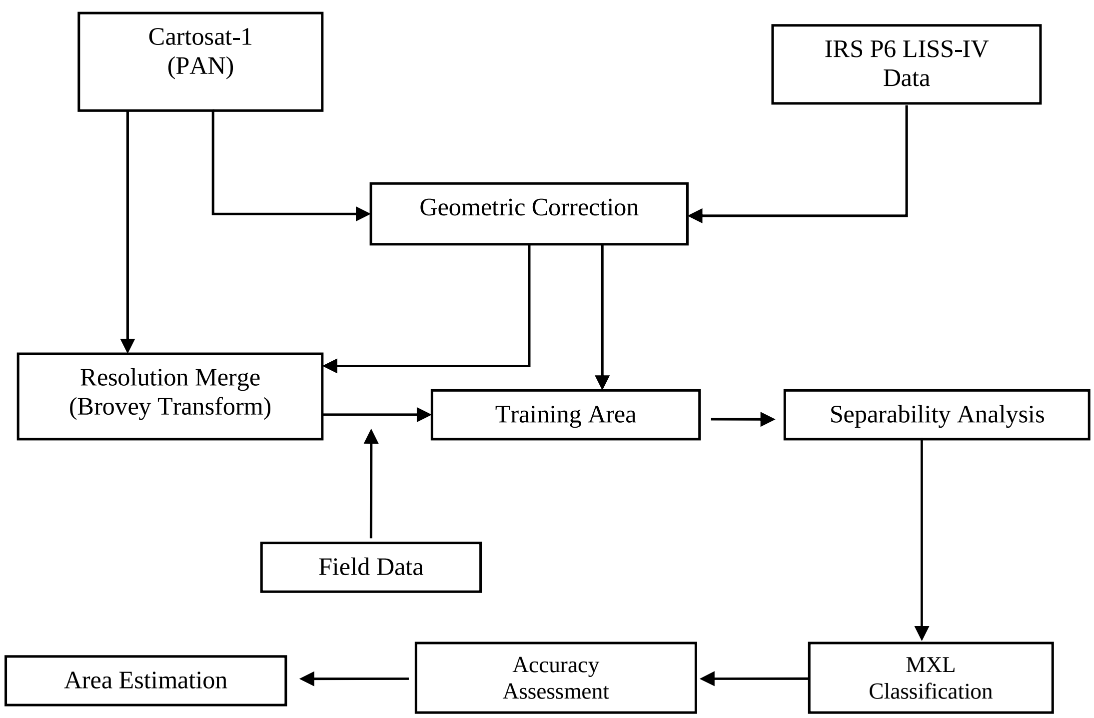

Fig. 2. Methodology used in the present study.

Table 1. Cartosat-1 and Resourcesat-1 LISS-IV sensor characteristics.

Satellite	Sensor	Bands	Spectral Coverage (nm)	Spatial Resolution (m)	Radiometric Resolution (bit)	Swath width (km)
IRS P6	LISS-IV	Band 4	1550-1700	70 x 70	7	148
		Band 1	520-590	5.8		23.9
		Band 2	620-680	5.8		
		Band 3	770-860	5.8		
IRS P5	Cartosat-1	PAN	500-850	2.5	10	30

tropical with temperature varying from 2.5 °C (winter) to 38.9 °C (summer). Monsoon spreads from July and October. The average annual rainfall is about 2183 mm. The relative humidity is high during the monsoon season, normally exceeding 70% on average. Along the river, flood plains and terraces, the soil texture varies from loamy sand to sandy clay loam. As per the classification by Champion & Seth (1968), the Subtropical Shiwalik Sal and Northern Tropical Dry Deciduous Forests are seen in the area.

Geo-rectification

The methodology used in the present study is shown in Fig. 2. The data sets used in the study and their specifications are given in Table 1. The orthorectified Cartosat-1 image was used as master image for geo-rectification of LISS-IV imagery using fifteen control points and second order polynomials. Sub-pixel registration accuracy was achieved after several iterations.

Image fusion and analysis

The Brovey transform (Zhou *et al.* 1998) was used to merge the LISS-IV and Cartosat-1 imagery. Spectral and statistical analysis was done for all the sensors under study. The minimum and maximum values, mean, standard deviation (SD) and the coefficient of variation (CV) for each band of different sensors and for different classes were calculated. The CV values were used for comparison. Fig. 3 shows visual comparison of merged imagery with component images.

Texture analysis

The gray level co-occurrence matrix (GLCM) method (Haralick 1986) with 3 x 3 pixel window size was employed for the generation of texture features. Six texture features, mean, variance, contrast, homogeneity, dissimilarity and entropy were generated from Cartosat-1 orthoimages and the NIR band of LISS-IV as input images. The mean, contrast and variance features exhibited maximum information and hence, were taken as input images for the classification. The NDVI layer generated from LISS-IV was used to mask out the non-forest area.

Classification and accuracy assessment

The common training sites selected from the

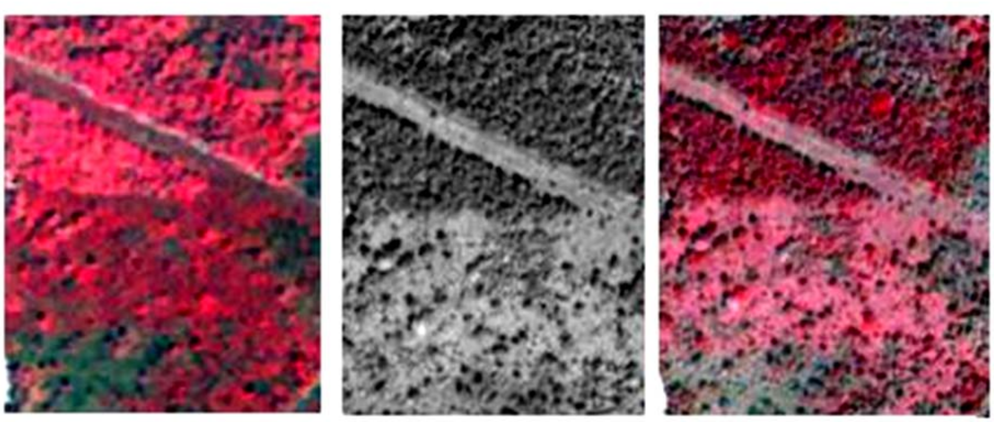

Fig. 3. Visual comparison of merged image with component images.

merged image were used for maximum likelihood classification of all images. The classified data was converted to vector data to compare the area under *Lantana* patches. The classified images were field-checked at 85 locations for classification accuracy assessment.

Results and discussion

Temporal analysis of September, February and April LISS-IV data (Fig. 4) was conducted to establish a trend in vegetation phenology and detect changes in community composition and canopy structure. In the month of September, sal forest maintained significant foliage which resulted in high reflectance from upper canopy and inhibited the reflectance from under story. Therefore, under story separation of *Lantana* was not possible from September to mid-December. Hence, LISS-IV images were not used for further analysis (hence, only Cartosat-1 imagery was used). Shedding of leaves in this forest occurred from mid-December to April. Due to partial shedding of leaves in the month of February, reflectance from the under story also added to the total reflectance (appear in light reddish tones on standard false color composite (FCC)). Though under story vegetation was visible in February image, boun-dary delineation was not possible.

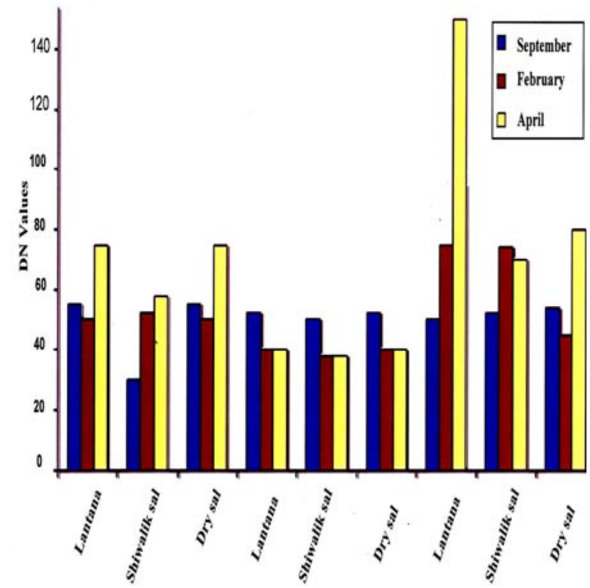

Fig. 4. Spectral reflectance of *Lantana* and others in February, April and September.

In the month of April, maximum reflectance occurred from the under story vegetation due to complete leaf shedding in dry sal and dry mixed deciduous forests. This pattern in reflectance showed that the data acquired from February to April months were suitable for detection of under

Table 2. Statistical analysis of spectral reflectance (DN values) from different vegetation classes.

	IRS LISS-IV			Cartosat-1+IRS LISS-IV		
	Band			Band		
	1	2	3	1	2	3
Lantana						
Minimum	47	43	82	47	43	82
Maximum	55	56	98	60	60	107
Mean	50	47	90	56	53	99
SD	1.8	3.6	3.2	2.0	2.1	3.8
CV	3.6	7.6	3.5	3.6	4.0	3.8
Shiwalik Sal						
Minimum	39	34	65	23	14	54
Maximum	57	56	120	54	50	109
Mean	48	42	92	39	32	77
SD	3.2	3.1	8.5	4.7	4.9	8
CV	6.6	7.3	9.3	12.2	15.3	10.4
Dry Sal						
Minimum	42	38	59	30	29	46
Maximum	58	65	95	61	66	93
Mean	52	55	77	47	52	73
SD	2.6	4.2	5.2	5.4	6.3	6.5
CV	5.0	7.7	6.8	11.6	12.0	8.9

Table 3. Transformed divergence values showing separability (higher values means greater separability).

Satellite Data	Bands	Average	Minimum	Class Pairs		
				1:2	1:3	2:3
IRS-P6	Band 1	1768	1532	1931	1532	1840
	Band 2	1919	1832	2000	1832	1924
	Band 3	1947	1841	2000	1841	2000
LISS-IV	Band 1	1992	1984	1992	1984	1999
	Band 2	1995	1986	2000	1999	1986
	Band 3	1999	1999	2000	1999	2000

1- *Lantana,* 2- Shiwalik sal, 3- Dry sal

storey *Lantana*. The best month varies each year due to annual differences in temperature and precipitation. The merged image and LISS-IV data were compared statistically for different vegetation classes (Table 2). In LISS-IV image, CV of *Lantana* was slightly lower than Shiwalik sal and dry sal, indicating that *Lantana* discrimination was possible to certain extent, although higher differences in CV facilitate more accurate discrimination. In the merged image, large differences in CV were found between *Lantana* and other forest classes, making it possible to differentiate the *Lantana* from the rest. The separability of various classes is shown in Table 3. The transformed divergence (TD) value of 2000 showed very good separability of *Lantana* from Shiwalik sal in bands 2 and 3 of LISS-IV data. The TD value of 1992 and 2000 between *Lantana* and dry sal in bands 1 and 2 respectively also showed good separability. Similar results were obtained using merged data.

The classification involving texture was helpful in successfully differentiating the *Lantana* from Shiwalik sal. Band 3 of LISS-IV had the maximum variability within the vegetation classes compared to the other two bands (Tables 2 & 3). Hence, band 3 was selected for texture analysis to extract *Lantana*. Classified output of LISS-IV showed a better separation of *Lantana* from other vegetation classes (Fig. 5) because it had a high spatial resolution of 5.8 m and the April data captured complete leaf fall and hence under storey vegetation was better discriminated. Since Cartosat-1 data is panchromatic data and lacks spectral information, the differentiation of vegetation classes could not be possible. The merged image facilitated better separation of *Lantana* due to the combined effect of both spectral and spatial information; this resulted in delineation of under storey vegetation. LISS-IV FCC yielded better results compared to LISS-IV and Cartosat-1 merged image.

Table 4. The producer's and user's accuracies.

Sensors	Classes	Producer's Accuracy	User's Accuracy
LISS-IV	*Lantana*	84.00	95.45
	Shiwalik sal	93.33	87.50
	Dry Sal	100.00	100.00
Cartosat-1	*Lantana*	91.30	87.50
	Shiwalik sal	50.00	56.52
	Dry sal	63.88	63.88
Cartosat-1 +LISS-IV	*Lantana*	100.00	92.20
	Shiwalik sal	96.88	96.67
	Dry sal	96.77	100.00

Table 5. Area (ha) estimated from the outputs of different sensors.

Sensors	*Lantana*	Shiwalik sal	Dry sal	Others	Total
LISS–IV	65	320	843.5	242.9	1417
Cartosat-1+LISS-IV	61	448.7	813.2	148.1	1417

Table 6. Number of patches of *Lantana* obtained using different data sets.

Sensors	No. of Polygons	Area (ha)	Minimum (ha)	Maximum (ha)
LISS-IV	24	65	0.6	11
Cartosat-1+LISS-IV	33	61	0.5	9

Accuracy was assessed for all the classified outputs to study the performance of the sensors in *Lantana* detection. Results showed that highest classification accuracy (96%) was obtained using the merged product. This was followed by LISS-IV (93%). Cartosat-1 resulted in poor accuracy of 65% as shown in Table 4. The classified outputs generated from the merged and the texture images are shown in Fig. 5. Area statistics derived from classified outputs using LISS-IV, Cartosat-1 and merged image are shown in Table 5. In LISS-IV and merged data, it was 65 and 61 ha respectively which significantly coincided with the forest department management maps.

When the area of the merged image was compared with that of the texture image of Cartosat-1, it was found that there was 10 ha difference. Texture image of NIR band of LISS-IV showed *Lantana* occupying an area of 66 ha, which was same as the area extracted from LISS-IV *i.e.* 65 ha. No significant change was found when the NIR band of LISS-IV has been subjected to texture analysis. It was found that as the spatial resolution increased, the minimum patch size decreased due to fragmentation. The LISS-IV showed a minimum patch size of 0.6 ha. The merged image showed minimum patch size of 0.5 ha, similar to LISS-IV (Table 6).

Conclusions

A trend in vegetation phenology and changes in species-community composition and canopy structures were established using temporal data (i.e. September, February and April months). Comparison of these three months data revealed that February to April were suitable months for detection of under story *L. camara* vegetation, due to full bloom of leaves in *Lantana* and shedding of leaves in sal, teak and mixed forests. The study has demonstrated the potential of LISS-IV and Cartosat-1 for detection and mapping of invasive species such as L. *camara* with desirable accuracy. The merged product has sharpened the boundary delineation of *L. camara* and its spread. Further improvement was obtained using textural information from Cartosat-1 to separate *Lantana* from mixed deciduous trees. This encouraging result demonstrated the feasibility of developing a semi-automated procedure to map and analyze the distribution of *Lantana* in forest areas and found to give better results as compared to high-resolution multispectral data.

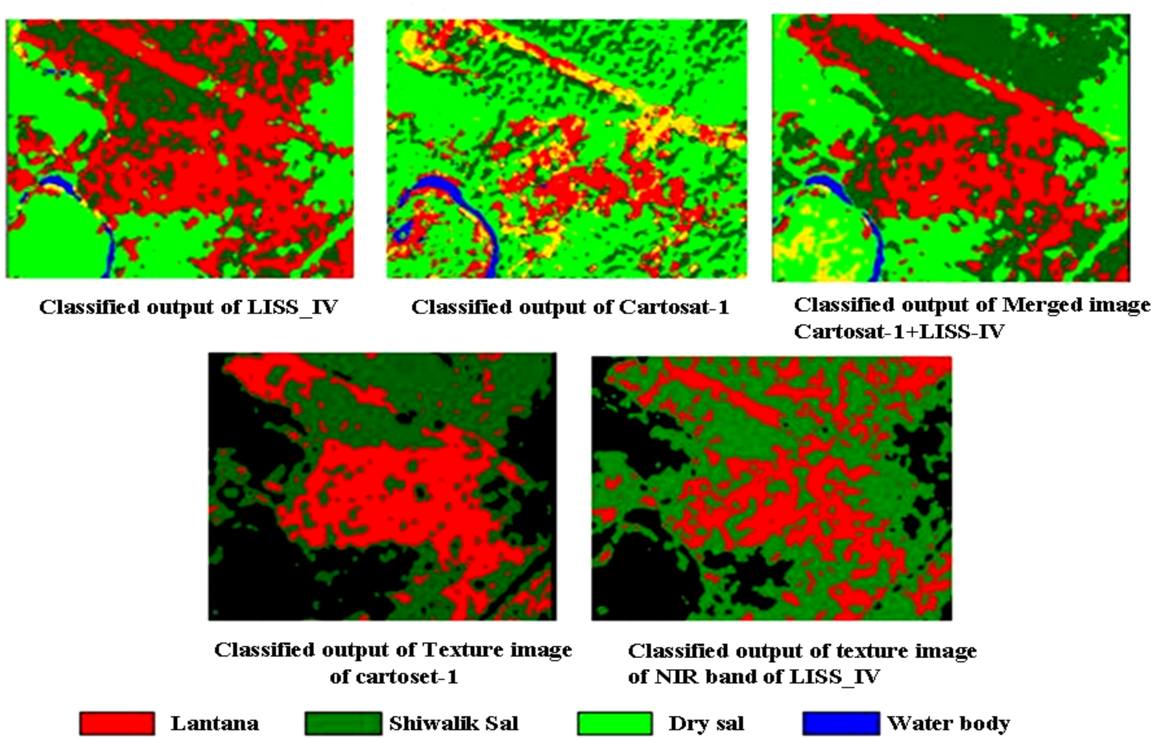

Fig. 5. Classified outputs of different sensors.

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