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Evaluation of various image fusion techniques and imaging scales for forest features interpretation

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The paper presents an objective evaluation of three image fusion techniques for interpretation of forest features in Pathri Reserve Forest, Hardwar. The three fusion techniques based on principal component substitution (PCS), intensity–hue–saturation transformation (IHS) and Brovey’s transformation were performed. The merged images were evaluated on three different scales, i.e. 1 : 50,000, 1 : 25,000 and 1 : 12,500. It was observed that PCS method of fusion presented the most suitable output, followed by Brovey’s and IHS, respectively. Further, it was also observed that output from the PCS method contained better information for discrimination of forest stand types. For interpretation of non-forest areas, i.e. grassland, agriculture, water bodies, IHS-based fusion was adjudged to be the best overall and maximum at the scale of 1 : 12,500. The study demonstrates higher capability of merged IRS LISS-III and PAN data products for differentiation and mapping of forest stands.

REMOTE sensing products are an effective medium for display of spatial information of different land cover features with different spectral characteristics.

Remote sensing data can be obtained in multi-sensor, multi-resolution, multi-frequency, multi-temporal forms, making the fusion or integration of data from various sources and of various kinds, easier. The use of multi-sensor image data is becoming an increasingly important component of digital image processing, since it increases

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a user's ability to simultaneously analyse complementary information. By digitally merging different data types, the synergetic characteristics of each data set can be exploited¹.

A typical multi-resolution satellite sensor works in several multi-spectral modes, along with panchromatic mode of higher spatial resolution. The additional information of the panchromatic band in combination with the multi-spectral bands, allows the retrieval of maximum image information from the given image data set. According to Pohl, Van Genderen and Wald, 'Image fusion is a process of performing the alliance of multi-scale, multi-spectral or multi-temporal remote sensing data and generating a new data with higher information content'. The main objectives of image fusion are improved image reliability (by redundant information) and also improved image capability (by complementary information). Ideally, the method used to merge data sets with high spatial and high spectral resolution should not distort the spectral characteristics of the high-spectral resolution data².

The availability of several currently-planned, air- and space-borne sensor missions have made image fusion a useful tool for image interpretation.

The integrated output of low-resolution multi-spectral data and high-resolution panchromatic data offers their respective advantages, for improved image classification in PAN + LISS combination³, substitution of missing information in VIR with SAR combination⁴ or for change detection in multi-temporal data sets⁵.

The present study illustrates the use of multi-spectral and multi-scale data on an area of 3952 ha located between 29°45'N–29°55'N latitude and 78°00'E–78°10'E longitude. The area represents the reserved forest of Pathri near Hardwar city in Uttaranchal, India. The main objectives of the study are to: (1) Extract useful information from the source images; (2) Not to introduce artifacts or inconsistencies which will distract human observers; (3) Be reliable and robust to imperfections such as misregistration.

The algorithms available for image fusion operate on a pixel-level, feature-level and decision-level. We concentrated on the pixel-based fusion which is performed at the level of spectral radiance values and offers minimum of original spectral information^{4,6}. This technique requires the input images to be registered with high accuracy of less than half a pixel, since misregistration can cause artificial colours in features of data, thereby leading to falsifying of interpretation. Image fusion techniques can be categorized into three types, colour-related, numerical/statistical-related and combined approaches. All colour-related techniques employ slicing of original data into their respective layers, which can be basic RGB, human-perceived IHS, HSV or more scientific luminance–chrominance. This is followed by substitution by a high-resolution image in place of one of these channels and a

back-transformation of this combination into the original RGB domain. The application specified decides on the choice of image channel to be substituted. The statistical method, as indicated by its name, uses a mathematical approach for data integration. It involves addition, multiplication, differencing, ratioing of low- and high-resolution data prior to their integration. Inclusion of weights and scaling factors helps in preservation of the original values. The basic purpose is to imbibe the spatial information of high-resolution data in the spectral realm of low-resolution multi-spectral data, keeping in mind the requirement of minimum loss of original information from either of the two data sets. The methods used to merge the information contents of both data sets were the IHS, PCS, Brovey's and multiplicative. Combined approaches involve integration of both statistical as well as colour-related techniques. One such approach employs the substitution of PC1 of multi-polarized SAR data in place of intensity component of multi-spectral data^{7,8}.

Resolution and scale have been important issues in the field of remote sensing application research. The concern primarily being the development of methods for determination of the most appropriate scale and resolution for studies on specific applications. In the process of selection of an image with appropriate spatial resolution, the changes in scene pattern and information content are observed to be a function of changes in scale and resolution. This paper attempts an evaluation of various image fusion techniques at varying image scales, to establish an optimum spatial resolution and imaging scale for greater quality interpretation of the area.

Within the spatial domain, four types of scales are identified in the literature; cartographic, geographic, operational and resolution scale⁹. We pursue our study with reference to the geographic scale, which is the spatial extent of the study area also termed as a 'domain' in ecological literature^{10,11}.

Remote sensing data contain various geometric and radiometric distortions, the rectification of which is a prerequisite to ensure compatibility of data on pixel-by-pixel basis for pixel-based image fusion. Random geometric distortions and unknown systematic geometric distortions are corrected by calculation of approximating polynomials using well-distributed ground control points (GCPs), occurring in the given data set of images.

The PAN and radiometrically-corrected LISS data were registered to the geocoded toposheet of the study area. The high-resolution panchromatic and low-resolution LISS data were registered on an image-to-image basis and hence geocoded with high accuracy (RMS error of 0.0001 pixel). After being resampled, the output false colour composite of LISS data is of the same dimension as the corresponding panchromatic image. The NIR band of original multi-spectral image was stretched linearly and stacked to produce a false colour composite. Three techniques were used to fuse the data and the outputs were

subjected to a standard deviation stretch of 1.7, to improve the visual interpretability. The processing was performed using model-maker module of ERDAS Imagine 8.4 and displayed using the map composition module of Imagine 8.4 installed in the Windows NT environment.

In case of Brovey's fusion, the three bands of LISS data were normalized by dividing all individual digital number (DN) values of LISS data with a sum of the corresponding DN values of all bands and multiplied to high-resolution channel, to incorporate the intensity or spatial component into the output.

$$DN_f = \frac{DN_{b1}}{DN_{b1} + DN_{b2} + DN_{b3}} * DN_{HR},$$

where $b_1 \dots b_n$ are the respective bands of multi-spectral data; HR stands for high resolution image; and f stands for fused image.

In case of PCS-based fusion, the LISS data were first subjected to principal component (PC) analysis in order to obtain the 1st PC with maximum variance. This PC was then replaced by the high resolution image channel which had been stretched to the variance and average of PC1. This combination was then transformed back into the RGB domain by inverse principal component analysis transformation. The resulting image was subjected to a rescaling procedure (0–255), to obtain the final fused output.

For IHS-based fusion, the LISS III data were subjected to an intensity–hue–saturation transformation (IHS) leading to extraction of three components of the original image. The intensity component representing the surface roughness or the spatial content of the LISS data was then replaced by the high resolution single-band panchromatic image channel, which was previously contrast-stretched to match the original intensity component. A reverse IHS transformation was then applied to obtain the final fused image with spectral context of original RGB image and spatial resolution of panchromatic data.

The equation for extraction of intensity component from original image is

$$|I| = [(1/3)^{1/2}(1/3)^{1/2}(1/3)^{1/2}] |R|,$$

$$|V_1| = [(1/6)^{1/2}(1/6)^{1/2}(-2/6)^{1/2}] |G|,$$

$$|V_2| = [(1/2)^{1/2} - (1/2)^{1/2} 0] |B|,$$

where I stands for intensity; and V_1 and V_2 are intermediate values used later for deriving hue and saturation.

A comparative study was carried out for spectral and spatial characteristics of the produced fused data sets. The observations made are presented visually and thus validated statistically.

All the three fused images were used for evaluation along with the original high-resolution PAN and multi-

spectral LISS III images. Two forest test sites (A and B) were recognized for visual comparison of forest features. The colour composites generated by original 2, 3, 4 bands of LISS data and by PCS fusion, IHS fusion and Brovey's fusion method are shown in Figures 1 and 2. The vector layer for the test sites is overlaid at the same location on each of the composites for visual comparison. This procedure² shows the colour differences of specific features, if they exist, in fused data sets as referred to the LISS-III data, and thus indicates whether the spectral characteristics of the target locations were distorted or changed by the method used for data integration.

It was thus seen that, for Figure 1 *a–d*, the Khair–Shisham association depicted as a class, held maximum similarity in colour to the LISS data for PCS-fused data set, whereas for IHS and Brovey's fused products, the colour of forest was distorted and gave a bluish reflectance, thus resulting in saturation of green and blue reflectance.

In Figure 2 *a–d*, the Shisham–Khair association class again showed maximum similarity of PCS-fused image with the LISS data, the other two images had a multicolour reflectance.

Another effort for comparison of three fused outputs was performed for the best interpretability in forest classes, at varying imaging scales. The procedure was performed for three scales, 1 : 50,000, 1 : 25,000 and 1 : 12,500, respectively. The output images are presented in Figure 3 *a–i*.

The improvement in quality of image interpretation is visually depicted, wherein IHS proves to be good for water- and moisture-related classes (swamps), but PCS gives the best results for forest classes, as required by the study. Brovey's method of fusion was found to be moderately suitable for all types of classes.

For assessment of preservance of spectral characteristics of multi-spectral input image using the provided three fusion methods, a comparative study of correlation coefficients¹² was performed (Table 1). It is thus clearly seen that PCS images for NIR band, i.e. for forest classes correlate well with original multi-spectral data, whereas correlation between IHS and Brovey's merged images and original data is significantly lower.

The basic assumption made by both IHS and PCS fusion methods is that PAN data are very similar to (i) intensity component of IHS domain, and (ii) PC1 of PCS domain; hence PAN replaces these components for final fused product (Figure 4 *a, b*). This assumption is validated statistically (Table 2), and it is observed that the correlation coefficient of PAN with intensity component is a bit higher than that of PC1. Hence IHS fusion method preserves the spatial components of PAN data better (Figure 4 *a, c*).

A statistical analysis of image interpretation of the fused products was performed for three scales, 1 : 50,000,

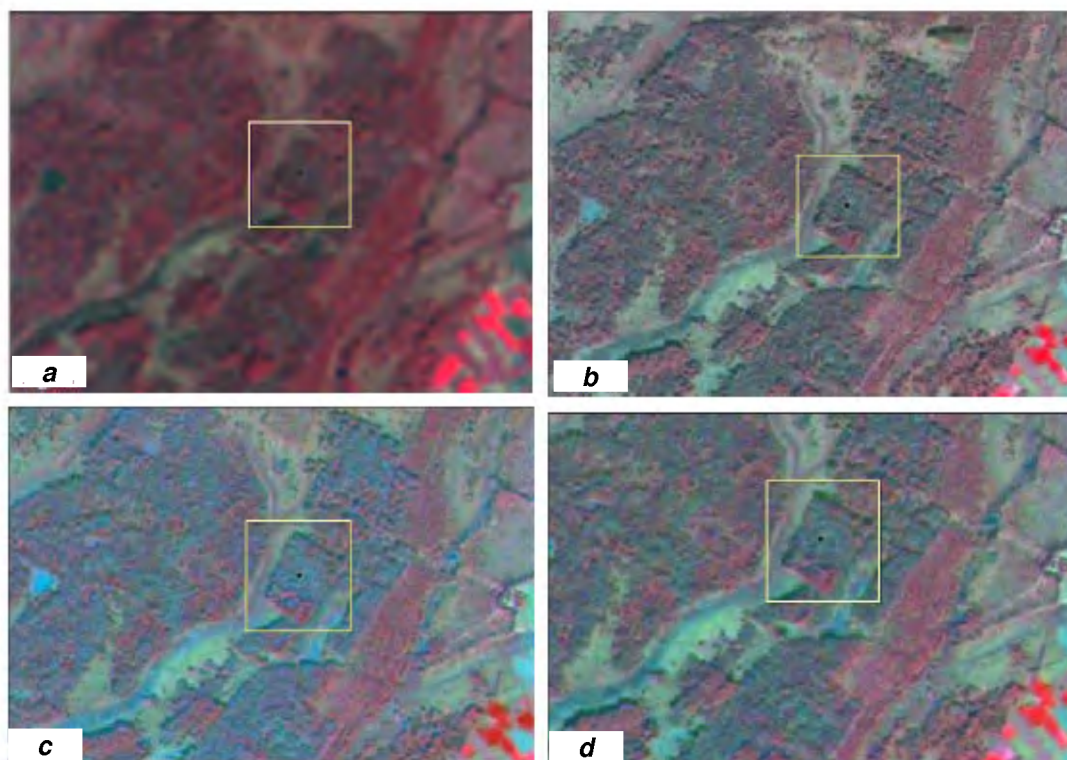


Figure 1. *a*, LISS image (Site-A); *b*, PCS-based fusion (Site-A); *c*, IHS-based fusion (Site-A); *d*, Brovey-based fusion (Site-A).

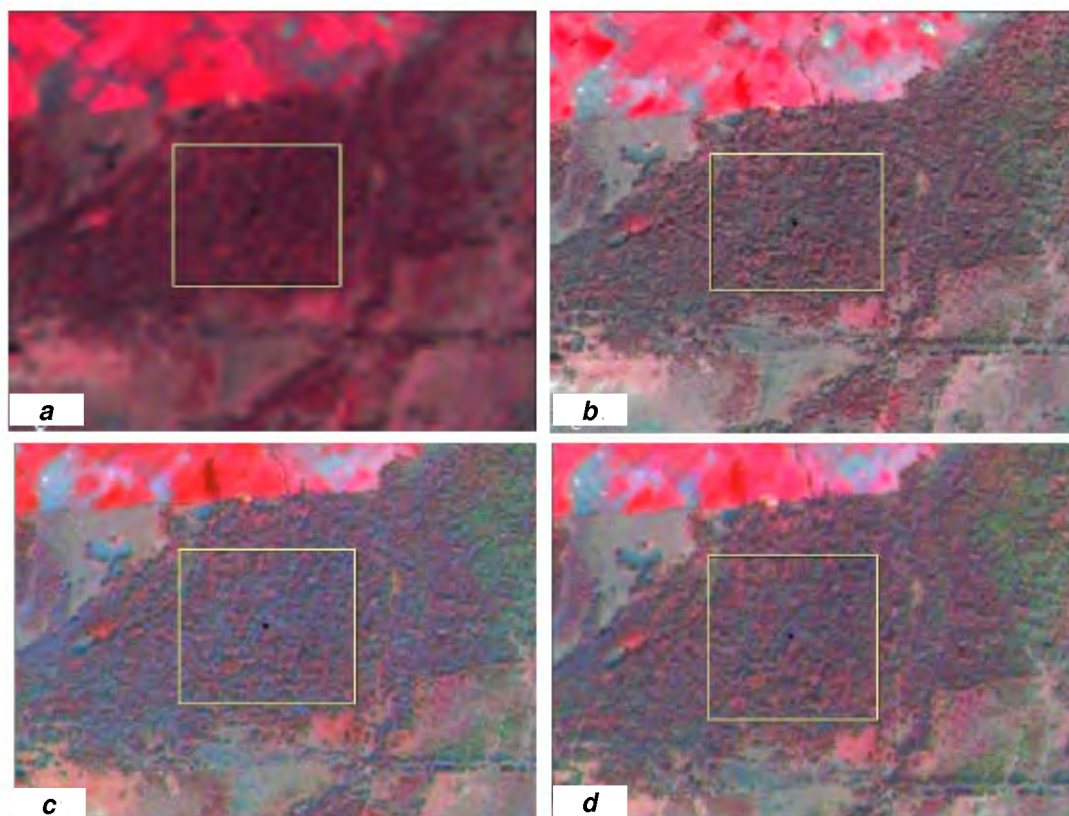
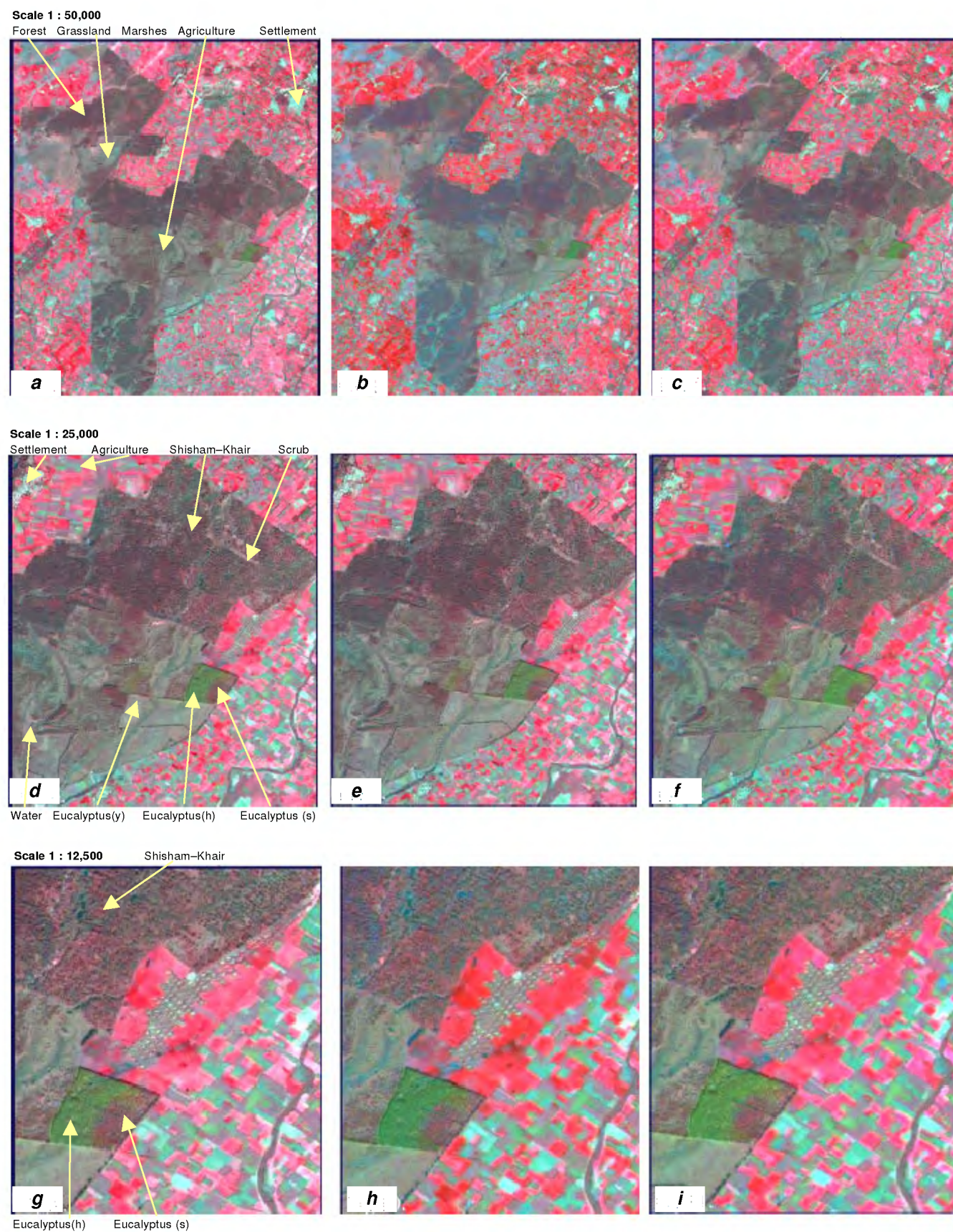


Figure 2. *a*, LISS image (Site-B); *b*, PCS-fused image (Site-B); *c*, IHS-fused image (Site-B); *d*, Brovey-fused image (Site B).



1 : 25,000 and 1 : 12,500, respectively, taking the Figure 3 *a–i* as reference. At the scale of 1 : 50,000 (Figure 3 *a–d*), five broad classes were considered for the study (Table 3), which showed that at this coarse scale, IHS-fused image gave best results for interpretability, except in forest classes for which PCS was better.

At the scale of 1 : 25,000 (Figure 3 *d–f*), a total of 12 forest and non-forest classes were recognized (Table 4), where PCS-fused image was noticeably best for maximum classes. Brovey's fused image gave the next best results and IHS gave the least, except for water, swamps, etc.

At the scale of 1 : 12,500 (Figure 3 *g–i*), the density of three forest classes was studied (Table 5), where PCS-

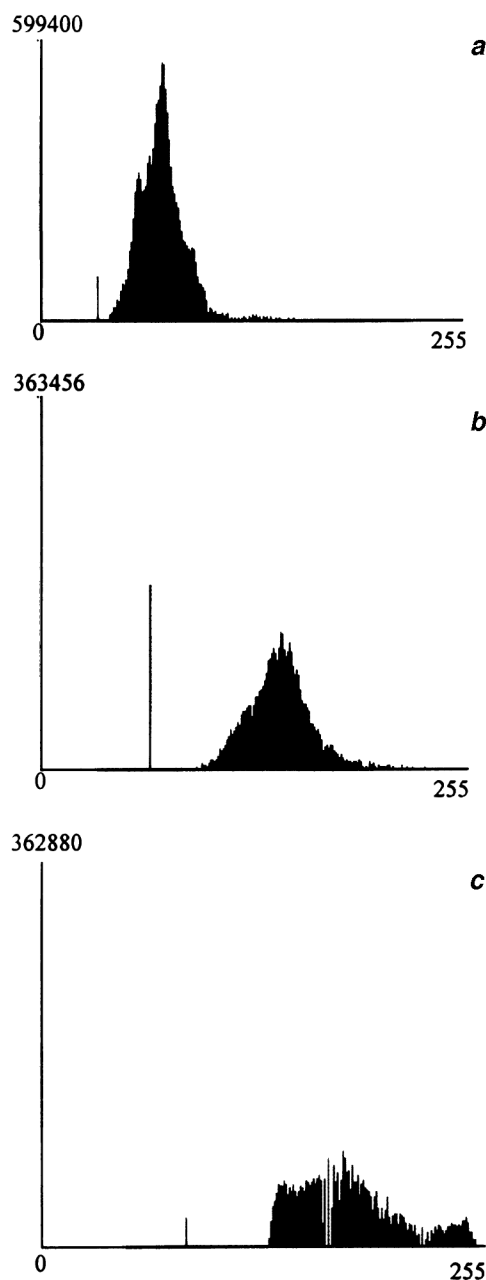


Figure 4. Histogram for *a*, PAN image; *b*, PCI image; and *c*, Intensity image.

Table 1. Correlation coefficients of fused images

LISS-III image bands	PCS	Brovey	IHS
Band 2 (Green)	0.77	0.79	0.76
Band 3 (Red)	0.79	0.860	0.85
Band 4 (NIR)	0.866	0.865	0.834

Table 2. Correlation coefficients of the intensity component of IHS domain and PC1 of principal components

High resolution image	Intensity component of IHS	PC1 of PCA
Panchromatic image	0.780	0.779

Table 3. Image interpretability of fused products at scale 1 : 50,000

Class	PCA	Brovey	IHS
Forest	✓✓✓	✓✓	✓
Barren	✓✓	✓	✓✓✓
Water	✓✓	✓	✓✓✓
Agriculture	✓✓	✓	✓✓✓
Settlement	✓✓	✓	✓✓✓

✓✓✓ High; ✓✓ Medium; ✓ Low.

Table 4. Interpretability of fused products at scale 1 : 25,000

Class	PCA	Brovey	IHS
Eucalyptus stand	✓✓✓	✓✓	✓✓
Eucalyptus young	✓✓✓	✓✓	✓✓
Eucalyptus felled	✓✓	✓✓	✓✓✓
Water	✓✓	✓	✓✓✓
Agriculture	✓✓	✓✓✓	✓✓
Settlement	✓✓✓	✓✓	✓✓
Khair–Shisham	✓✓✓	✓✓	✓
Scrub	✓✓✓	✓✓	✓
Miscellaneous	✓✓✓	✓✓	✓✓✓
Shisham–Teak–Khair	✓✓	✓	✓✓
Shisham–Khair	✓✓✓	✓✓	✓
Swamps	✓✓	✓	✓✓✓

✓✓✓ High; ✓✓ Medium; ✓ Low.

Table 5. Interpretability of fused products at scale 1 : 12,500

Class	PCA	Brovey	IHS
Eucalyptus (S) Density (medium)	✓✓✓	✓	✓✓
Eucalyptus (Y) Density (high)	✓✓✓	✓	✓✓
Shisham–Khair Density (medium)	✓✓✓	✓	✓

✓✓✓ High; ✓✓ Medium; ✓ Low.

fused product presented clear distinct forest stands and hence interpretable density. IHS-fused product gave the next best result, followed by Brovey's product.

The decision to choose the most suitable technique is influenced by specified application and can be supported by statistical validations. The PCS method should not be applied when correlation is small and replacing bands is not advantageous, if spatial resolution differs by a factor greater than two.

It has been widely observed in earlier research that IHS has become a standard procedure in image analysis, since it provides colour enhancement of highly correlated data¹³ and improvement of spatial resolution^{14,15}. IHS method has been recommended for different spatial and spectral resolution data^{2,16,17}. IHS has the most effective and controlled visual presentation of the data, since other techniques produce images which are difficult to interpret quantitatively and qualitatively, as the statistical properties have been manipulated and original integrity of data is lost¹⁸.

According to the present study, IHS method of data fusion distorted the data most in terms of spectral characteristics, but was very good at preserving the spatial components of high-resolution data sets. Brovey's method highly distorted the spectral value, but PCS fusion method changed the spectral values to the least, comparatively.

Also the PCS method was found to be good for visual interpretation of data at high scales, giving a high-resolution image of clear spectral values, making feature identification very easy. At the scale of 1 : 12,500, PCS-fused image presented a very clearly demarcated forest canopy and was thus appropriate for forest density stratification.

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Possible relationship between temporal electrical resistivity variation and occurrence of the earthquake of 30 September 1993 in Latur region, Maharashtra, India

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A lack of precise understanding of the complex earthquake processes has come in the way of earthquake prediction. It is well established that the hypocentral region of an earthquake undergoes structural and geological changes prior to its occurrence, leading to variation in physical properties of the rocks. In the present paper, the electrical resistivity measurements in and around Latur, Maharashtra, India from 1984 to the present time bring out an interesting correlation between earthquake occurrences and resistivity values. In intraplate stable continental regions like Latur where the possible location is broadly known, the temporal variations of electrical resistivity may zero down the period of occurrence of high magnitude earthquakes to a couple of months.

THE earthquake precursors and earthquake prediction are the burning issues among the earth scientists and engineers. Referring to a large number of important studies, Geller¹ has reviewed the investigations carried out in this

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