B. Additive and Multiplicative Technique

1) Brovey Transform:

The Brovey transform, named after the it's author. Ratio images are very useful in change detection. The Brovey transform is a formula based process that is based on the band to display in a given colour, the sum of all the colour layers, and the intensity layer. The Brovey transform uses a formula that normalizes multispectral bands used for an RGB display, and multiplies the result by any other higher resolution image to add the intensity or brightness component to the image. The formula is as follows:

$$R = (R / (R + G + B)) * I$$
$$G = (G / (R + G + B)) * I \quad (5)$$
$$B = (B / (R + G + B)) * I$$

Where, R = Red, G = Green, B = Blue, I = Intensity
The Brovey transform can also be expressed as,

$$DN_{fussed\ MSI} = \frac{DN_b}{DNb_1 + DNb_2 + \dots + DNb_n} DNpan \quad \dots (6)$$

The Brovey transform provides excellent contrast in the image domain but affects the spectral characteristics a great deal [4], [17].

2) Multiplicative Technique (MT):

The multiplicative technique (MT) is grouped under the arithmetic method which uses the four possible arithmetic methods (addition, subtraction, division and multiplication) to incorporate an intensity image into an achromatic image. The MT algorithm is based on the following relation,

$$DN\ R\ (new) = DNR * DN\ PAN$$
$$DN\ g\ (new) = DN\ g * DN\ PAN \quad (7)$$
$$DN\ B\ (new) = DN\ B * DN\ PAN$$

Where, DN*R*, DN*G* and DN*B* = Digital number of the corresponding pixel belonging to the R, G and B bands

DN PAN = Digital number of the corresponding pixel belonging to the panchromatic band

DN new = New digital number of the corresponding pixel of the respective band

3) Colour normalised (CN) transformation:

The colour normalised transformation [6] fuses the two spectral and spatial data sets assuming there is a certain spectral overlap between the multispectral bands and the more highly resolved panchromatic band. This constraint is violated for the near infrared band XS3 and results in poor fusion results. Equation (5) shows the merging process whereby the additive constants avoid division by zero.

$$XS_i^R = \frac{3(XS_i^R + 1)(P_N + 1)}{\sum_I XS_i^R + 3} - 1 \quad (8)$$

C. Wavelet Method

The wavelet transform [6], [7], [8], [10], [16] is a mathematical tool extensively used in image analysis and image fusion. Using multi-resolution analysis, the multispectral and the panchromatic images were decomposed into an orthogonal wavelet representation at a coarser resolution, which consisted of low frequency approximation image and a set of high frequency detail images. The detail images from the high resolution panchromatic image are incorporated into the decomposed multispectral images at a level the resolution of the ground cover matches and the inverse transform is taken.

The various steps involved in merging images using wavelet method are as follows;

- Resample the multispectral image to make its pixels size equal to that of the panchromatic images. The multispectral and panchromatic images are geometrically corrected using ground control points, so that they can be merged.
- Apply the discrete Wavelet transform to the "histogram-matched" panchromatic image and to the "resampled" multispectral image, using the Daubechies four coefficient wavelet basis. Four half-resolution images (C_a, C_h, C_v and C_d) are obtained from each multispectral and panchromatic full resolution image.
- Repeat step 2 to generate wavelets for each level till the resolution of the image matches by using the approximation image as input for each level.
- Using the detail images (C_h , C_v and C_d) from each decomposition, generate the detail images that are going to be replaced in the multispectral decomposition.

The detail images can be generated using the following formula;

$$C_h^* = (C_h^p + C_h^m)/2$$
$$C_V^* = (C_v^p + C_v^m)/2 \quad \dots\dots \quad (9)$$
$$C_d^* = (C_d^p + C_d^m)/2$$

Where, C_h^*, C_v^*, C_d^* are the detail images generated that are going to be replaced in the multi-spectral decomposition.

C_h^p, C_v^p, C_d^p are the detail images generated from the panchromatic data.

C_h^m, C_v^m, C_d^m are the detail images generated from the multi-spectral data

D. Filter Fusion Method:

1) High-pass Filter Fusion Method (HPF)

High-pass filter fusion method a method that make the high frequency components of high-resolution panchromatic image superimposed on low resolution multispectral image, to obtain the enhanced spatial resolution multispectral image. The formula is as follows**:**

$$F_k(i,j)=M_k(i,j)+HPH(i,j) \quad (10)$$

In the formula, $F_k(i,j)$ is the fusion value of the band K pixel (i,j), $M_k(i,j)$ the value of multi-special of band k pixel (i,j), HPH(i.j) show the high frequency information of the high resolution image.

2) Smoothing Filter-based Intensity Modulation:

Smoothing Filter-based Intensity Modulation, which a brightness transformation is based on the smoothing filter. The formula of this arithmetic is as follows:

$$B_{SFIM\ I} = \sum_J \sum_K \frac{B_{LOWr\ ,k} \times B_{HIGHf\ ,k}}{B_{MEANf\ ,k}} \quad (11)$$

In the formula B_{sfim} is the fusion image generated by this arithmetic, I is the value of the band, J and K is the value of row and line; B_{LOW} is the Low-resolution images, B_{MEAN} is simulate low-resolution images, which can be obtained by low-pass filter.

E. Fusion Based on Interband Relation

1) Regression fusion (RF):

Due to the high correlation between the visible bands, the relation between one of the fused visible wavelength range images and the high resolution band can be expressed by the simple regression shown in Equation (12). The bias parameter a_i and the scaling parameter b_i can be calculated by a least squares approach between the resampled band XS^R i and P_N.

$$XS_i^H = a + b * p_{1 \dots n} \qquad \dots\dots (12)$$

The regression technique is not suitable for the near infrared band since the global correlation is weak. However, significant improvements can be obtained using a local approach. Instead of computing the global regression parameters, the a_i and b_i parameters are determined in a sliding window.

2) Look-up-table (LUT) Fusion:

The regression method suffers even for local processing of the near infrared band from the use of the least squares approach. A non-linear approach like the use of lookup-tables helps to overcome this deficit. The up-sampled versions of the multispectral bands are compared with the corresponding high-resolution pixels using a local pixel neighbourhood. Finally the radiance values of the bands XSRi are manipulated with respect to the generated tables. Care must be exercised in choosing the size of the neighbourhood and in preventing artifacts.

IV. EVALUATION OF FUSION TECHNIQUES

A. Qualitative Evaluation (Visual Analysis)

The resulting images obtained from different conventional techniques had erosion scars and some of the deposition areas enhanced related to the other targets in the images. PCA looks much closer to Multi-spectral band in colour hence look more vivid in PCA than BT. Further, PCA is brighter than BT and MT; MT looks dull and smoky. Next to PCA it is the BT which is closer to Multi-spectral data. In brightness retaining quality too the fusion technique is found to be bright and better preserving the original Multi-spectral details. When all the visual evaluation are put together, the PCA is found to be bright and better in preserving the original Multi-spectral details; the BT ranked the second and MT stand in the last in retaining spectral quality. However for these approaches one can verify that it was not possible to obtain a good detail. For example, grass, natural fields and vegetation cover in the early growing stage were not well discriminated. It was also possible to notice a defocusing in the images, which made the erosion scars look like stains instead of linear feature [3], [19].

Among the conventional techniques, it was observed that PCA seems to give the best result of image fusion. Discrete Wavelet fused image has a "better look" evident the erosion scars, showing them with clear and pale tones. Due to preservation of spectral characteristics, it was possible to discriminate more precisely other targets existing in the image. After the spatial resolution enhancement, it was also possible to identify several small features of landslides and the colour scheme is also as good as the original image that were not identified using other fusion approach [3], [19].

TABLE III
VISUAL ANALYSIS OF FUSION METHODS

Methods	Color Recovery	Sharpness
PCA	Good	Good
BT	Good	Not Acceptable
MT	Not Acceptable	Not Acceptable
DWT	Very Good	Very good

As already mentioned, due to limitation of human vision in terms of distinguishing the number of grey levels, comparison and appreciation by visual method doesn't reveal the exact potentials of the fusion methods. Hence comparison of image statistics was attempted to evaluate the results of fusion using PCA, BT, MT, and discrete wavelet transform methods. It is believed that such a comparison would accurately quantify the loss of information after fusion.

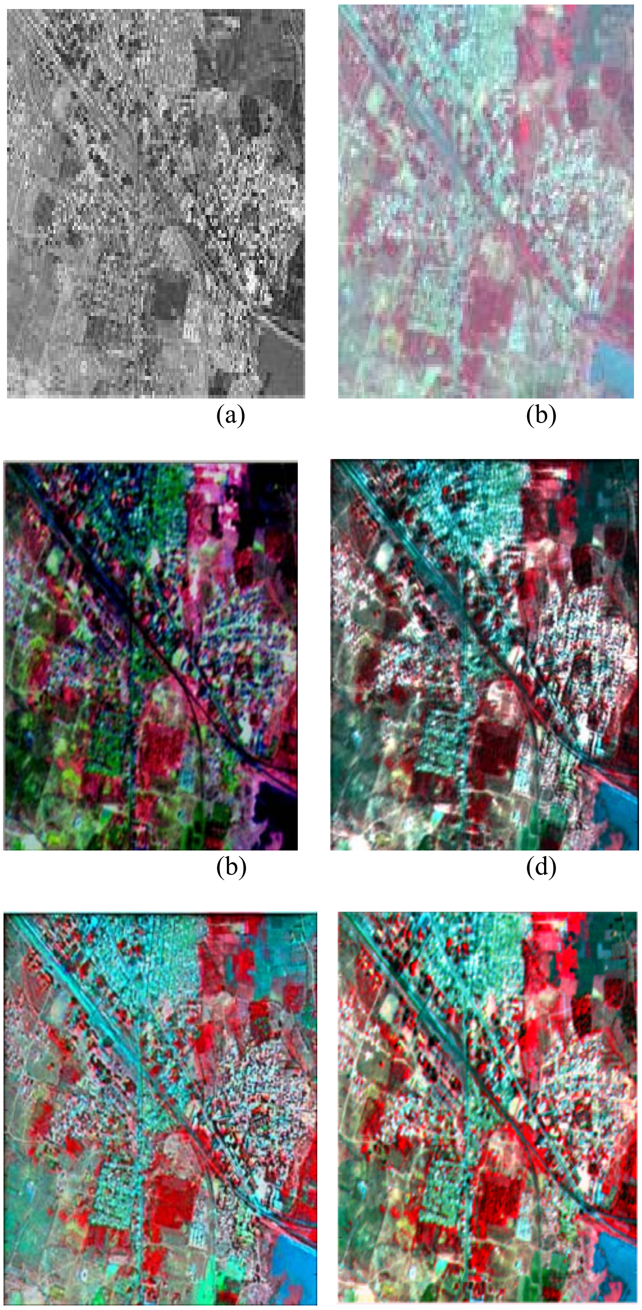
B. Quantitative Evaluation (Spatial and Spectral)

Spatial quality evaluation of the fused image is a more complex task and usually based on perceptual inspection. It can be clearly observed from the fused images that all the image fusion methods sharpen the respective multi-spectral bands. Regarding the preservation of spatial resolution, all discussed image fusion methods behave very similarly. However, a greater resemblance between the panchromatic and the intensity image doesn't mean better preservation of spatial resolution [5], [20].

TABLE IV
VISUAL ANALYSIS OF FUSION METHODS

Fusion Methods	RMSE
BT	62.6215
PCA	56.5499
MT	48.6398
DWT	41.0478

From the result, it can be clearly seen that proposed fusion technique is in agreement with previous literature. For the spatial changes, PCA method of fusion has more spatial variation compared to other technique. Hence image fusion is always a trade off between the spectral information of the multi-spectral image and spatial information of the panchromatic band. It is shown that Multiplicative and Brovey transform has more spectral changes. As PCA preserves the spectral changes as in the multi-spectral images, the multi-pectral changes are less in the DWT fusion method. Hence it is shown that DWT method of image fusion is best in preserving the spectral content when compared to PCA, BT, MT methods of image fusion. Image fusion methods used in this work is easier to evaluate the contribution of these components in the fused image and to choose the appropriate fusion method which satisfies the user need.



(a) (b)

(b) (d)

(e) (f)

Fig. 4 Snapshot of (a) Panchromatic Image (b) Multispectral Image (c) Principal Component Analysis (d) Multiplicative Technique (e) Brovey Transform (f) Discrete Wavelet Transform Fused Images.

V. CONCLUSIONS

The image fusion methods are used to generate high resolution image that attempts to preserve the spectral characteristics of the original data. There are no generalized criteria for the selection of a particular fusion technique. The selection of the fusion method for an application depends largely on the dataset. For image fusion methods, spatial enhancement and spectral preservation are all critical issues.

In this paper, a new image fusion method is introduced. The fusion outcome is regarded as a linear combination of the input panchromatic and multispectral images. Experimentation with images collected by different sensors reveals that the proposed method is satisfactory. The DWT fusion method presents the best result for both visual and quantitative evaluations. This can be explained by the improvement of the spatial resolution and preservation of the spectral information. Moreover, the DWT method maintains the high spectral content with respect to the original multispectral images. Besides it shows the good spatial content to give an output which is “better looking”.

The spatial and spectral changes help in comparative study of various fusion techniques. It has been proved that PCA fusion technique preserves more spectral information as compared with Multiplicative and Brovey Image fusion techniques. The Multiplicative fusion technique preserves more spatial information as compared with PCA and

Brovey image fusion techniques. Apart from this, the Discrete Wavelet transform yielded better results when compared with the PCA, BT and MT image fusion image. The proposed method has a very smooth transition among different geographic features; however, other fusion methods produce blocking artifacts in the fused images.

The comparative analysis was carried out between the PCA, BT, MT and DWT. The DWT image showed significant improvement for the erosion scars and debris deposition areas identification. Although this approach did show good results for the identification of erosion scars, it is still necessary to evaluate its potential in other areas where such phenomena occurs, and to test the images obtained from other sensors.

techniques. The Discrete Wavelet transform technique is proved to be the best of all the fusion techniques irrespective of the characteristics of the

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