Multi-Sensor, Multi-Resolution and Multi-Temporal Satellite Data Fusion for Soil Type Classification

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ABSTRACT
Digital soil type classification and its mapping is challenging task for many applications. The soil classification is essential for agriculture for crop growth and food production. Single sensor and low resolution satellite images do not provide the details about soils. Data fusion of remote sensing images is a promising way to solve many applications like soil classification. In the present paper, pixel level image fusion techniques were focused. The multi-sensor, multi-date and multi-resolution satellite imagery was used for present research using data from IRS-P6 LISS-III and LISS-IV sensors acquired on 23 October 2008 and 28 February 2014 having spatial resolution 23.5m and 5.8m respectively. The Gram-Schmidt spectral sharpening and the PC spectral sharpening the two techniques, were implemented for soil type classification. Generally, satellite image fusion is carried out via high spatial resolution panchromatic image with low spatial resolution multispectral image, but in the current research a novel approach via considering both multispectral images were proposed. The NIR band from high spatial resolution LISS-IV image and low spatial resolution LISS-III image with all four bands were considered for image fusion. Since no yet study has been executed for image fusion from both multispectral images in remote sensing. The classification was performed on the fused images using minimum distance to means classifier. The results show that when applied minimum distance classifier using the Gram-Schmidt spectral sharpening method 74.30% overall accuracy with Kappa Coefficient 0.70 and 68.71% overall accuracy of the PC spectral sharpening method with Kappa Coefficient 0.63 were achieved.

General Terms
Satellite image fusion, Gram-Schmidt spectral sharpening method, PC spectral sharpening method.

Keywords
Soil classification, satellite image fusion, minimum distance to means classifier.

1. INTRODUCTION
Soil is the primary natural resources. Soil type classification is one of the most important parameters of crop growth. The groupings of soils with their properties into units which are geo-referenced and mapped are generally known as soil classification. Soil classification is challenging task, because soils are a very complex in nature [1]. For the agricultural applications, classification of various types of soil with its geo-referencing and mapping is crucial. Soil classification and its mapping via satellite images is a helpful tool for focused agriculture for food production. Recently, remote sensing satellite images have been providing valuable information on the planet with fine spatial and spectral resolution timely and cost-effective way [2]. But, only single sensor and single low spatial resolution images are not given, the more details of complex structural features like soils. Hence, to overcome the limitations of single sensor low spatial and spectral resolution images, fusion of images are necessary to identify the various patterns effectively. The combination of two or more various images to form a new image via enhanced methods is termed as image fusion. The main target of image fusion is that to amalgamate fine resolution single band, i.e. panchromatic (PAN) image with low resolution multispectral image for developing a new high resolution image. Recent satellite sensors are increasing with various spatial and spectral resolutions, thus the image fusion technique gives the capability to map land cover with more interpretation abilities and more accurate results. Generally image fusion can be executed at three levels of fusion such as pixel (iconic) level, feature level and decision or knowledge level [3], [4], [5], [6].
Globe observation satellites grants various spatial, spectral and temporal resolutions which are beneficial for mapping terrain surface objects at glance to solve the real world challenges. Since image fusion techniques used in the last decades has been producing challenging applications in remote sensing [7]. Applications related to soil mapping are essential in crop management, landform management and soil planning for sustainable growth of the agricultural area. For the local planning and assessment, soil record is regularly carried out along with their spatial distribution [8]. And also conventional soil mapping and laboratory methods are time consuming, expensive and they could not provide spatial coverage and temporal changeability [9]. The digital soil classification and mapping is quite challenging due to mixed features problem on the earth's surface. In this contest, remote sensing image fusion is an efficient way for classification and mapping of soils through high spatial and spectral resolution satellite images.
In this paper, a new method which combines information from various satellites having different resolutions was proposed.

The section two indicates the study area, whereas section tree and four shows used materials and methodology with results and discussion.

2. STUDY AREA

The size of the study area Aurangabad is near about 123 km^2 (47 sq) located on N 19° 53' 47" and E 75° 23' 54". The city is enclosed by hills on all directions and historical places like Ajanta Ellora caves [10], [11]. The study region is complex in nature, having more hilly areas which cause the misclassification of soils. Fig. 1 [12] represents the geographical location of the study area.

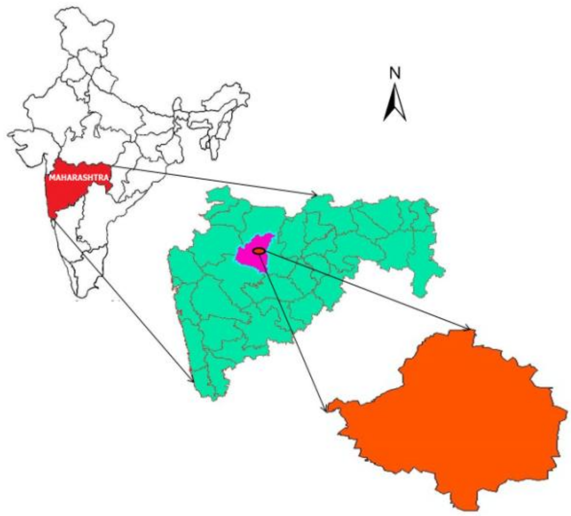

Fig 1: Geographical location of study area

3. MATERIALS AND METHODS

3.1 Datasets

For this study, IRS- P6 LISS (Linear Imaging and Self Scanning Sensor)-III satellite image of Aurangabad region was obtained from Bhuvan web portal (prepared by NRSC Balanagar, Hyderabad) of dated 23 October 2008. The LISS-III satellite imagery has four bands with 23.5 meter moderate spatial resolution and a swath of 141km. The high spatial resolution multispectral image acquired by the IRS-P6 LISS IV satellite of dated 28 February 2014 was used for image fusion with three spectral bands with 5.8 meter fine spatial resolution and a swath 70km. The Survey of India Toposheet E43D05 at 1:50,000 scales were used to prepare base map. Field data were also collected by GPS (Global Positioning System) and ground truth points were matched with Google earth and Google map.

3.2 Proposed Methodology

The ENVI 4.4 and ArcGIS 10 software's have been used for visual interpretation, image fusion, classification and analysis of data. For the present study, orthocorrected (geometric as well as radiometric corrected) satellite imagery from NRSC, Hyderabad was used. Standard False Color Composite (FCC) of geometrically corrected satellite images were generated after the data fusion for better visual interpretation. The overall proposed methodology for this study is shown in Fig. 2, and the method is discussed in the following sections.

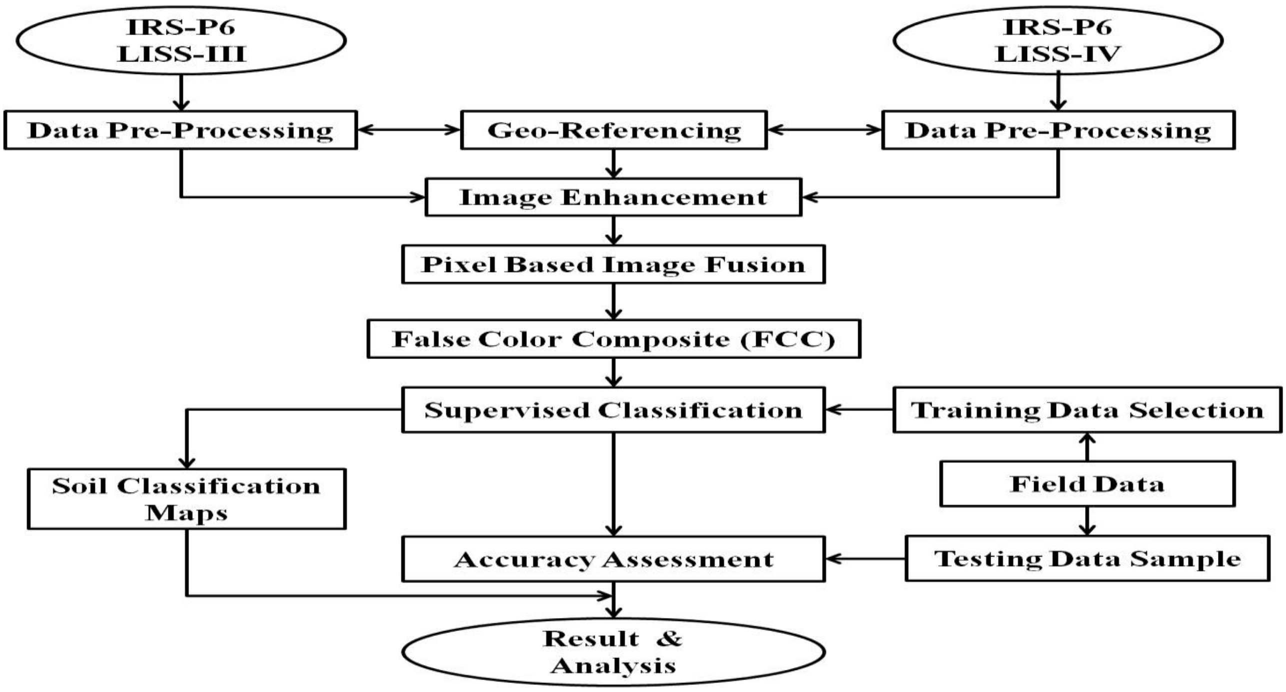

Fig 2: Workflow of proposed Methodology

3.2.1 Pixel Based Image Fusion

This fusion technique is based on the pixels in the satellite imagery. Generally multiplying or subtracting low resolution multispectral satellite images with fine resolution panchromatic satellite images, pixel based fusion is considered. In this work, the Gram-Schmidt spectral sharpening and the PC spectral sharpening image fusion algorithms were performed.

3.2.1.1 Gram-Schmidt Spectral Sharpening
This algorithm is used to reduce the redundancy and sharpen multispectral satellite imagery using fine spatial resolution satellite image. The Gram-Schmidt method is typically more accurate because it uses the spectral response function of a given sensor to estimate what the panchromatic image look like. From multispectral bands simulated single band is transferred whereas implementation is performed on the simulated single band and the spectral bands as the first band [5].

3.2.1.2 PC Spectral Sharpening
This algorithm is similar to the Gram-Schmidt transformation algorithm. It considers fine spatial resolution panchromatic image to sharpen a low spatial resolution multispectral image. The low spatial resolution spectral bands correspond to the high spatial resolution single band according to the technique [13]. Minimum distance to means classifier as a supervised approach on fused satellite images was performed to improve the accuracy of the soil classification through confusion matrix.

3.2.2 Minimum Distance to Mean Classifier
The minimum distance to means supervised classification is based on the average or mean spectral values in each class signature. It does not consider the standard deviation and covariance matrix in computation. It considers spectral distance between image and class in multi-feature space to classify the minimum distance as a maximum similarity [9], [12], [14]. It is computed using the equation 1 [15].

$$d(C_j) = \sqrt{\sum_{i=1}^{n}[DN(i,j)-C_{ij}]^2} \tag{1}$$

This calculation is repeated m times with all information classes, for each pixel in the input image data [15].

4. RESULTS AND DISCUSSIONS
Results suggested that, data related to LISS-III and LISS-IV is suitable for image fusion. For the Gram-Schmidt spectral sharpening and the PC spectral sharpening methods, firstly LISS-III data with four bands as a low resolution image, whereas three band data from LISS-IV were utilized. The NIR band as a high resolution image was selected. The studied region was mostly occupied by natural vegetations as well as agricultural crops.

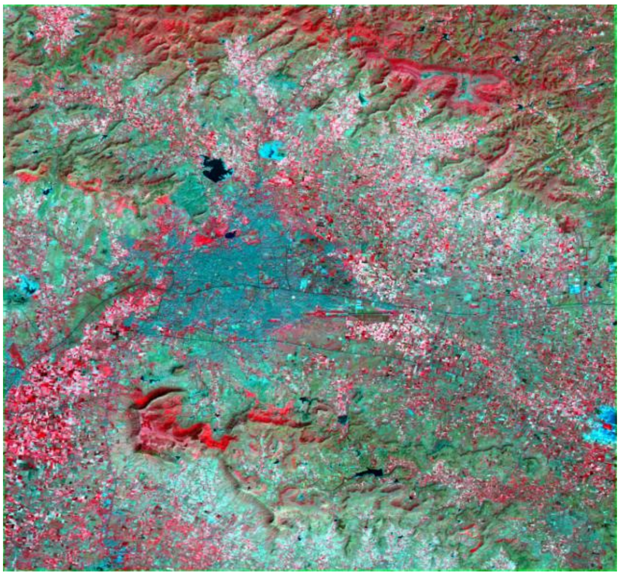

Fig 3: Image as obtained by the Gram-Schmidt spectral sharpening method

In this case, NIR band from high spatial resolution LISS-IV image was considered to distinguish soils with vegetations. The soil features were extracted from a SWIR band of low resolution LISS-III image. The final fused image of the Gram-Schmidt spectral sharpening and the PC spectral sharpening are shown in Fig. 3 and 4 respectively.

When applied minimum distance classifier on these two fused images, better results were obtained from the Gram-Schmidt spectral sharpening method than the PC spectral sharpening method. The following Figs. 5 and 6 show the classified images obtained by the Gram-Schmidt fusion and the PC spectral sharpening method respectively.

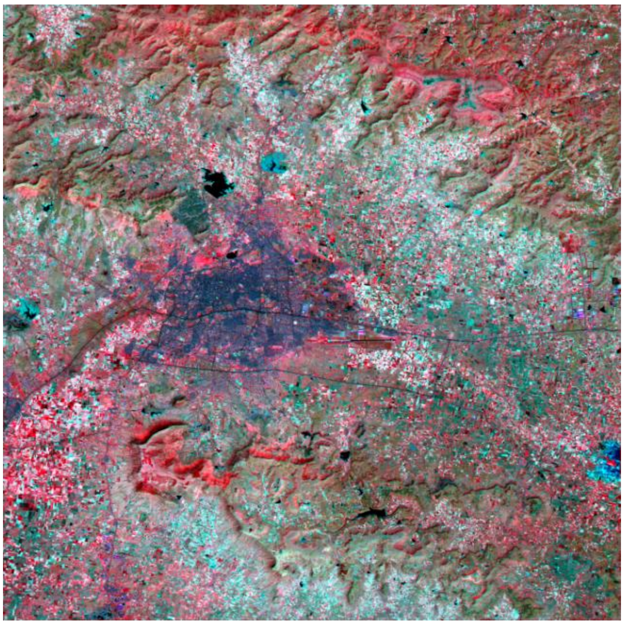

Fig 4: Image as obtained by the PC spectral sharpening method

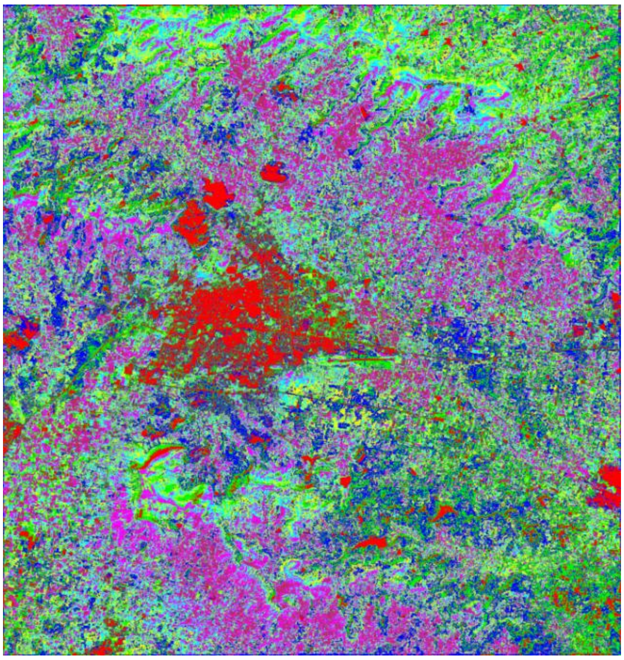

Fig 5: Classified Image as obtained by Minimum Distance on the Gram-Schmidt spectral sharpening method

Confusion matrix for minimum distance to means supervised classifier for accuracy assessment was used to calculate overall accuracy, user's accuracy with producer's accuracy and kappa coefficient listed in Table 1 and 2 respectively. 179 random points were selected to generate confusion matrix. The collected ground truth points were assigned for all different classes while considering the size of the studied region for selecting the number of ground truth points.

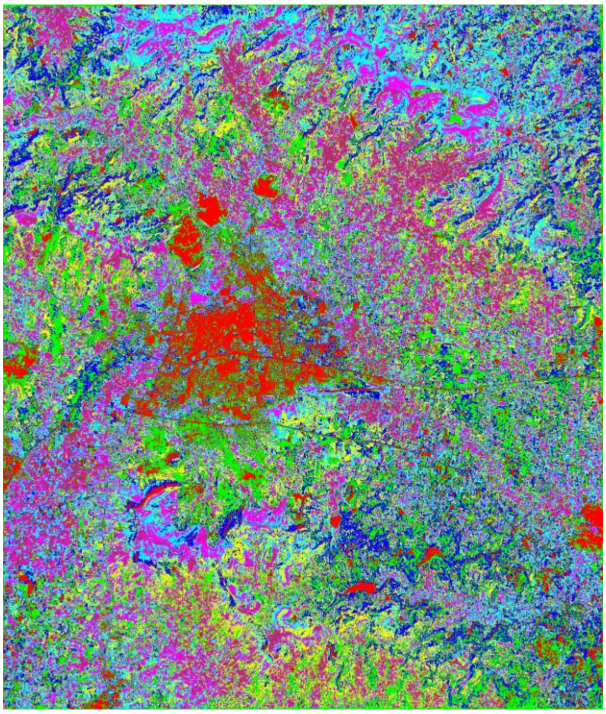

Fig 6: Classified Image as obtained by Minimum Distance on the PC spectral sharpening method

Table 1. Confusion Matrix for Minimum Distance Classifier on Gram- Schmidt Spectral Sharpening

Class	Ground Truth (Pixels)								
	AC1	**BSS1**	**BlS S1**	**BlC S1**	**BrS1**	**Veg1**	**Settel1**	**WB1**	**Total**
A_C	**21**	0	0	0	0	0	0	0	21
Br_SS	0	**13**	0	0	1	2	0	0	16
Bl_SS	0	1	**26**	0	0	0	3	0	30
Bl_CS	0	0	1	**19**	0	1	3	0	24
Br_S	3	5	0	0	**27**	0	0	0	35
Veg	0	1	3	8	0	**16**	5	0	33
Sett	0	0	0	0	0	0	**0**	9	9
W_B	0	0	0	0	0	0	0	**11**	11
Total	24	20	30	27	28	19	11	20	**179**

AC1 (A_C) - Agricultural_Crops, **BSS1 (Br_SS)**-Brown_Sandy_Soil, **BlSS1 (Bl_SS)**-Black_Sandy_Soil, **BlCS1 (Bl_CS)**-Black_Clay_Soil, **BrS1 (Br_S)**-Bare_Soil, **Veg1 (Veg)**-Vegetations, **Settel1 (Sett) -** Settlement, **WB1 (W_B) -** Water_Body.

The diagonal elements of the confusion matrix are the training set pixels that were correctly classified into their classes. The overall accuracy and kappa coefficient results with user's accuracy and producer's accuracy corresponding to the different class results obtained are summarized in Table 3.

According to accuracy assessment results, overall accuracy of the minimum distance classifier for the Gram-Schmidt spectral sharpening method was 74.30% with Kappa Coefficient 0.70 and for the PC spectral sharpening method it was 68.71% with Kappa Coefficient 0.63.

Table 2. Confusion Matrix for Minimum Distance Classifier on PC Spectral Sharpening

Class	Ground Truth (Pixels)								
	AC1	**BSS1**	**BlS S1**	**BlC S1**	**BrS1**	**Veg1**	**Settel1**	**WB1**	**Total**
A_C	**22**	0	0	0	1	0	0	0	23
Br_SS	0	**6**	0	0	1	2	0	2	11
Bl_SS	0	0	**26**	5	0	0	2	0	33
Bl_CS	0	1	4	**13**	0	1	2	0	21
Br_S	2	5	0	0	**24**	0	0	0	31
Veg	0	1	0	9	0	**14**	7	0	31
Sett	0	7	0	0	2	2	**0**	0	11
W_B	0	0	0	0	0	0	0	**18**	18
Total	24	20	30	27	28	19	11	20	**179**

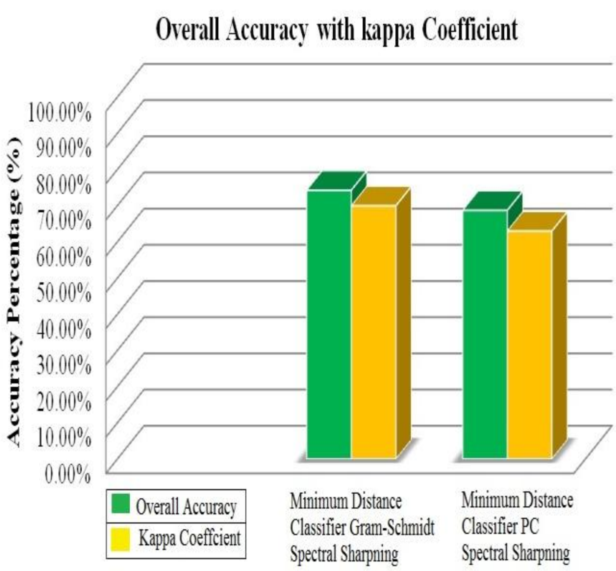

Fig 7: Overall Accuracy with Kappa Coefficient

Fig. 7 illustrates that, the overall accuracy and the Kappa coefficient of minimum distance classifier achieved by Gram-Schmidt spectral sharpening and PC spectral sharpening. It is observed that, the computed algorithms have given good accuracy for considering both multispectral satellite images for soil classification.

Table 3. Accuracy Assessment of Classifier (In %)

Classes	Minimum Distance Classifier Gram-Schmidt spectral sharpening				Minimum Distance Classifier PC spectral sharpening			
	Prod. Acc.	User Acc.	Overall Accuracy	Kappa Coefficient	Prod. Acc.	User Acc.	Overall Accuracy	Kappa Coefficient
A_C1	87.50	100.00	74.30	0.70	91.67	95.65	68.71	0.63
Br_SS	65.00	81.25			30.00	54.55		
Bl_SS	86.67	86.67			86.67	78.79		
Bl_CS	70.37	79.17			48.15	61.90		
Br_S	96.43	77.14			85.71	77.42		
Veg	84.21	48.48			73.68	45.16		
Sett	0.00	0.00			0.00	0.00		
W_B	55.00	100.00			90.00	100.00		

5. CONCLUSION

In this paper, low resolution and high resolution multispectral satellite imagery for image fusion based on pixels were considered. The results are significant for soil analysis of complex region. These two datasets were multi sensor, multi temporal and multi resolution. In remote sensing, data fusion plays a significant role for image interpretation and various pattern classifications. The outcomes of the study indicate that, Gram-Schmidt spectral sharpening algorithm gives better results than PC spectral sharpening according to classification results such as 74.30% and 68.71% respectively. In the future, present research may be effectively useful for low spatial resolution Hyperspectral and high spatial resolution multispectral image fusion.

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