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Simple ETM+ gap fill techniques review

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Abstract. In 2003 scan-line corrector (SLC) of the Landsat 7 Enhanced Thermal Mapper Plus (ETM+) sensor suffered major failure. Efforts that NASA made to correct the SLC malfunction have not been successful and the problem appears to be permanent. Without the operating SLC there are gaps in images, ranging as large as 14 pixels near the edges. Since 2003, a number of gap filling methods have been developed. First method being reviewed fill gaps for display only, called Focal Analysis. Second method, which is more complex, is convenient for scientific analysis, called Localized Linear Histogram Match (LLHM) and uses geo statistical approach to fill gap pixels. First method, Focal Analysis, is not satisfactory for any further analysis, where as the other method, LLHM, delivers good results achieved by geo statistical calculation.

Key words: Landsat 7, Enhanced thermal mapper plus, SLC failure, Geo statistical method, Focal Analysis, LLHM

1. INTRODUCTION

In 1972, first of the Landsat mission satellites has been launched. Since then, Landsat satellites have been collecting imagery of the Earth's surface. First of them, ERTS[1]-A, renamed to Landsat 1, operated from July 23, 1972 to January6, 1978. Second satellite was ERTS-B, renamed to Landsat 2, operated from January 22, 1975 to February 25, 1982.On March 5, 1978 Landsat C (also known as Landsat 3) was launched and was in operation until March 31, 1983. Landsat 4 (also known as Landsat-D) was launched on July 16, 1982 and operated until June 15, 2001. Landsat 5 was launched on March 1, 1984 and was in operation until June 5, 2013. Landsat 6 was launched on October 5, 1993, but did not achieve its orbit. The first Landsat with panchromatic band was Landsat 7. It was launched on April 15, 1999 and is still operational. On February 11, 2013 latest Landsat 8 was launched and still operational[4].

The Earth observing instrument on Landsat 7, the Enhanced Thematic Mapper Plus (ETM+), replicates the capabilities of the highly successful Thematic Mapper instruments on Landsat 4 and 5[11].

Additional features in ETM+ are:

- a panchromatic band with 15m spatial resolution
- on-board, full aperture, 5% absolute radiometric calibration
- a thermal IR channel with 60m spatial resolution
- an on-board data recorder [11].

On May 31, 2003, the scan-line corrector (SLC) of ETM+ failed permanently, which caused roughly 22% of the pixels to be un-scanned in any ETM+ images (referred to as SLC-off images)[1], and the ETM+ resumed its global land survey mission but with impact on the Landsat 7 imagery. The Scan Line Corrector (SLC) assembly is used to remove the "zigzag" motion of the imaging field of view produced by the combination of the along- and across-track motion. Without an operating SLC, the ETM+ line of sight now traces a zigzag pattern across the satellite ground track [11].

Nevertheless of SLC-Off mode, the ETM+ still acquires approximately 78 percent of the data for any given scene. Without the operating SLC, there are resulting gaps on images ranging as large as 14 pixels near the edges[6](Figure 1).Since the failure of SLC on

Landsat 7, and the gaps on the bands, many methods were developed to fill the existing gaps[8]. The main goal in this paper is to present two different gap filling methods in images recorded by ETM+ sensor of Landsat 7 satellite.

2. MATERIALS AND METHODS

In order to compare the methods, this study use the same location data set with different temporal mark in the paper. Main materials for gap fill methods were downloaded via USGS earth explorer application [9] WRS_PATH=186 and WRS_ROW=029. Landsat 8 data which will be used was acquired on June 12, 2015. Landsat 7 data used were acquired on June 4, 2015 and May19, 2015. For additional analysis Landsat 7 data from June 16, 2002 was obtained. Line gaps are noticeable in both footages acquired after May 31, 2003 (Figure 1).

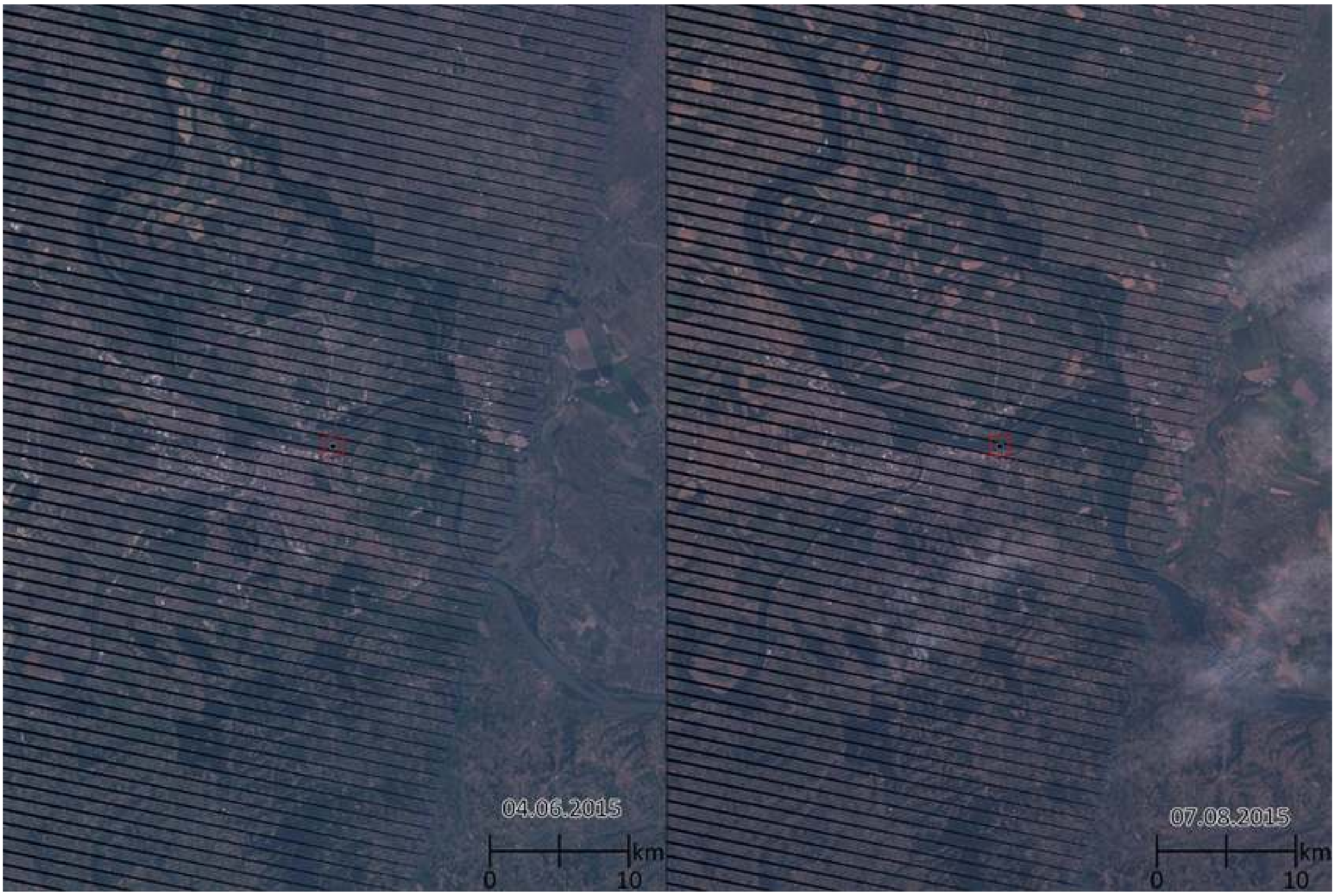

Figure 1. Landsat 7 ETM+ Color Composite

The center of research area is located within the coordinates 44° 49' 39.1543"N, 20° 31' 11.5292"E.

For both methods to be accomplished, topographic and atmospheric correction of satellite images was performed.

First method in this review study is commonly used to obtain data only for displaying, and is called Focal Analysis method. This method is designed to modify neighboring pixels in a single Landsat 7 SLC-off scene, creating a final *aesthetic* image only - no scientific analysis accuracy is guaranteed using this method [12].

We are going to use single scene to fill the gaps using Focal Analysis method. Focal Analysis evaluates the region surrounding the pixel of interest (center pixel) (Fig. 2).The operations which can be performed on the pixel of interest include: Standard Deviation, Sum, Mean, Median, Min, Max. These functions allow you to select the size of surrounding region to evaluate by selecting the pixel window size. This method with Median Filter model is useful for reducing noise such as random spikes in data sets, dead sensor striping, and other impulse imperfections in any type of image. Median Filter model is operating with a 3x3 pixel moving window size by default [10].Median filtering is a nonlinear signal processing technique that is useful for noise suppression in images. Algorithm for this model put all pixel Digital Numbers (DNs) with the selected moving window into numerical order and replace the pixel of interest with the DN value in the center of the ranking [4].

Second method being studied is used to derive data for Scientific Analysis. This method is called Mosaic Method [13]. At least two SLC-off images are required to utilize this method. A linear transform is applied to the "filling" image to adjust missing digital numbers (DNs) based on the standard deviation and mean values of each band, of each scene.

Filling the scan gap requires precise knowledge of what pixels are valid in an image and which are to be filled. A scan gap mask is created for each band. Existing data is marked as 1 and missing data in the scan gap and fill regions as 0. Once the gaps are located, the linear histogram matching methodology attempts to find a linear transformation between one image and another [5].

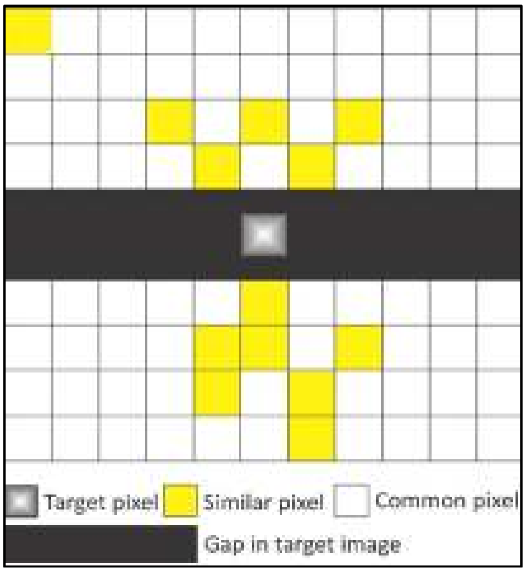

Figure 2. Similar pixel selection for single image gap method (Chen et al. 2011)

Localized linear histogram match (LLHM) method was used to fill the pixel values of the SLC-Off image to be filled (the 'primary scene') by applying a corrective gain and bias to the pixel values of an SLC-On image(the 'fill scene'). Relations between scenes is shown in figure 3.

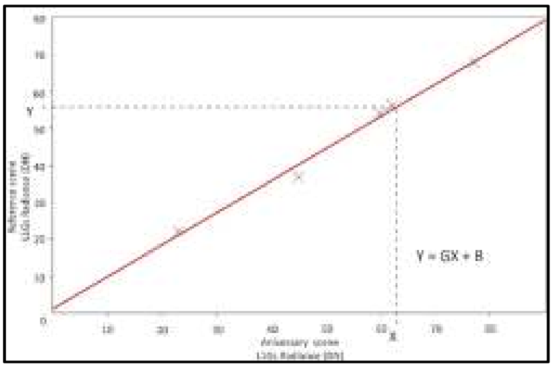

Figure 3. Linear relation between scenes (Scaramuzza et al. 2004)

With a SLC-On fill scene X and a SLC-Off primary scene Y, we make the assumption

that:

$Y \approx GX + B$

where

G = the gain used to histogram match the fill image to the primary image.

B = the bias used to histogram match the fill image to the primary image.

X = the fill (SLC-On) scene array.

Y = the primary (SLC-Off) scene array.

The gain and bias can be calculated using the standard deviation and mean of arrays Xand Y:

$$G = \sigma_Y/\sigma_X$$

$$B = \bar{Y} - G\bar{X}$$

where

σ_X = the standard deviation of data in fill image X.

σ_Y = the standard deviation of data in primary image Y.

$\bar{X}$ = the mean of the fill (SLC-On) scene array.

$\bar{Y}$ = the mean of the primary (SLC-Off) scene array[5].

Appropriate exclusions are made, and the corrective gain and bias are calculated and applied to the center pixel value from the fill scene. The resulting value is used to fill the missing pixel in the primary image (Figure4).

Obtained data from both methods will be used for supervised maximum likelihood (Maxlike) classification analysis and afterwards will be compared to the classes obtained from the corresponding Landsat 8 images.

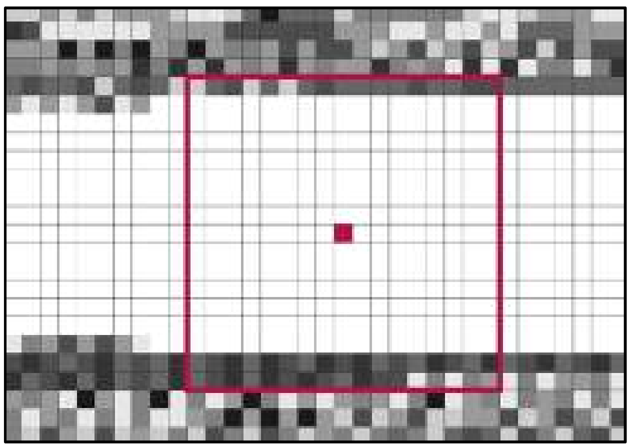

Figure 4. ETM+ gap fill LLHM method (Scaramuzza et al. 2004)

The Maxlike decision rule is based on the probability that a pixel belongs to a particular class. The basic equation assumes that these probabilities are equal for all classes, and that the input band shave normal distributions.

If you have a priori knowledge that the probabilities are not equal for all classes, you can specify weight factors for particular classes. This variation of the maximum likelihood decision rule is known as the Bayesian decision rule [3]. Unless you have a priori knowledge of the probabilities, it is recommended that they not be specified. In this case, these weights default to 1.0 in the equation.

The equation for the maximum likelihood/Bayesian classifier is as follows:

$D = \ln(a_c) - [0.5 \ln(|Cov_c|)] - [0.5 (X-M_c)T (Cov_c^{-1}) (X-M_c)]$

Where:

D = weighted distance (likelihood)

c = a particular class

X = the measurement vector of the candidate pixel

M_c = the mean vector of the sample of class c

a_c = percent probability that any candidate pixel is a member of class c (defaults to 1.0, or is entered from a priori knowledge)

Cov_c = the covariance matrix of the pixels in the sample of class c

$|Cov_c|$ = determinant of Cov_c (matrix algebra)

Cov_c^{-1} = inverse of Cov_c (matrix algebra)

ln = natural logarithm function

T = transposition function (matrix algebra).

The inverse and determinant of a matrix, along with the difference and transposition of vectors, would be explained in a textbook of matrix algebra.

The pixel is assigned to the class, *c*, for which *D* is the lowest[10].

Additional analysis using LLHM method was perform to display the results acquired by combination of Landsat 7 SLC-On image from 2002 and SLC-Off image from 2015 (Figure 10). Area will be classified as Urban area, Water, Cultivated land and Forest.

3. RESULTS AND DISCUSSION

Results of performed line gap fill is presented in fallowing figures. Figure 5 presents reference color composite and supervised classification image from Landsat 8 satellite which will be used for comparison of analyzed data. Since the main objective is not supervised classification of the area, there for the obtained data is not precise and serve just as comparison for different gap fill techniques. Figure 6 represents Focal Analysis gap removal process, from stage 1 to final stage 4 where all the gaps are removed.

Acquired result of this two gap filling methods are presented in figure 7 as color composite images. Focal Analysis method gives clean image whereas the LLHM method is dappled with lines in the North West area. Figure 8 represents supervised Maxlike classification of Focal Analysis gap fill data (A) and LLHM data (B). In some parts of the classified images is noticeable the existence of line gaps which disrupt the original condition of the area. Figure 9 presents tree different supervised classification images, from L8 (A), L7 Focal Analysis (B) and LLHM (C). The disrupt areas are marked with ellipsoids.As it can be seen in figure, Focal Analysis method gives good results in color composite mode. Picture looks clean, and the gaps are removed (Fig. 6 A4). Further analysis shows the disturbance in the data acquired by this method.

Final comparisons shows that color composite is much better, with no gaps from the data acquired by Focal Analysis method, but supervised classification reveals that there are a major disturbances in classified data as seen in figured 9B (ellipsoid marked areas). Although there are remaining gaps in the data acquired by LLHM, calculated data is more precise as we can see in figure 9C. Disrupt areas in image obtained using LLHM method are formed due to insufficient data from SLC-On image and overlapping gaps from both used images. Additional analysis using LLHM method presents that gap free SLC-On image is better option for gap filling (Figure 10 A). After the appliance of LLHM method, gaps are still noticeable. This LLHM method, even performed using SLC-On image, can’t give good results, since small portions of gaps and disrupt areas are still noticeable (Figure 10 B). Results are better compared to other two filled images, but still not satisfactory.

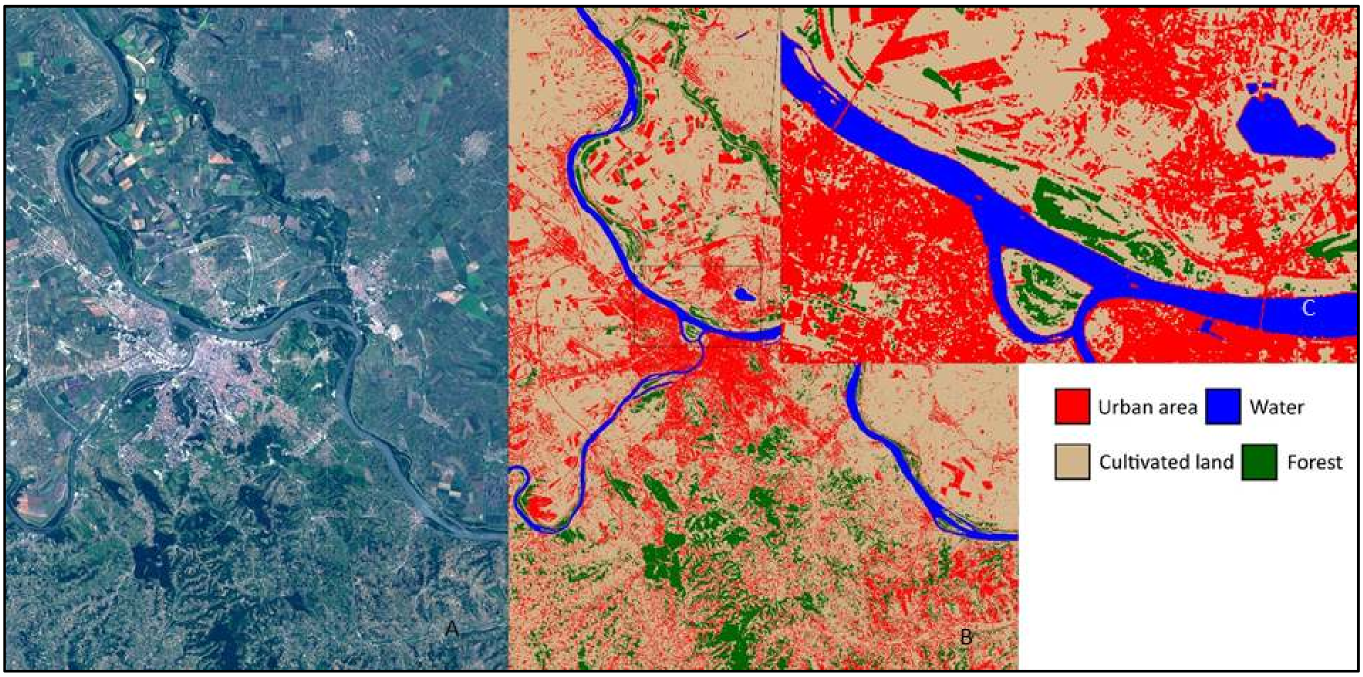

Figure 5. Landsat 8 images, **A** Color composite **B** Supervised classification, **C** Enlarged view of compared area

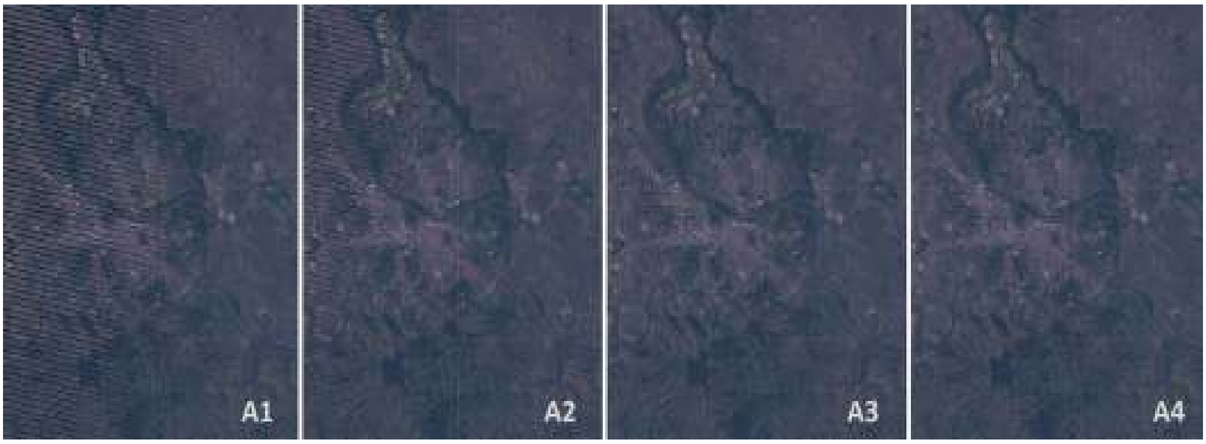

Figure 6. Focal Analysis gap removal. **A1** SLC off image **A2**, **A3** gap fill stage **A4** Focal Analysis gap clean image

Figure 7. Color composite. Gap fill final result. **A** Focal Analysis **B** LLHM

According to Scaramuzza, known algorithm limitations are:

– The adaptive local linear histogram adjustment algorithm can yield poor results if the scenes being combined exhibit radical differences in target radiance due to the presence of clouds, snow, or sun glint.

– Clouds present in the primary SLC-Off scene tend to pull nearby fill scene data to high bias levels so that the fill scene data appear "cloud-like" even if the scene is, in fact, cloud- free. This creates a superficially reasonable-looking gap-filled image but discards any benefit to be gained from the cloud-free fill scene data in the primary scene cloud areas. Fill scene clouds also cause problems for the algorithm. In addition to inserting cloudy "wedges" into otherwise cloud-free primary scene imagery, where fill scene clouds overlap valid primary scene data, the gain and bias computations are corrupted for nearby pixels. When these bright fill scene pixels are compared to the corresponding darker primary scene pixels, the resulting gain and bias adjustments will tend to reduce the fill scene image DN value. This leads to dark areas in the fill regions in the neighborhood of fill scene clouds.

– Similar effects can be expected wherever large changes in scene content and radian ceoccur, such as changes in snow cover or specular reflection off water due to changes in solar illumination geometry.

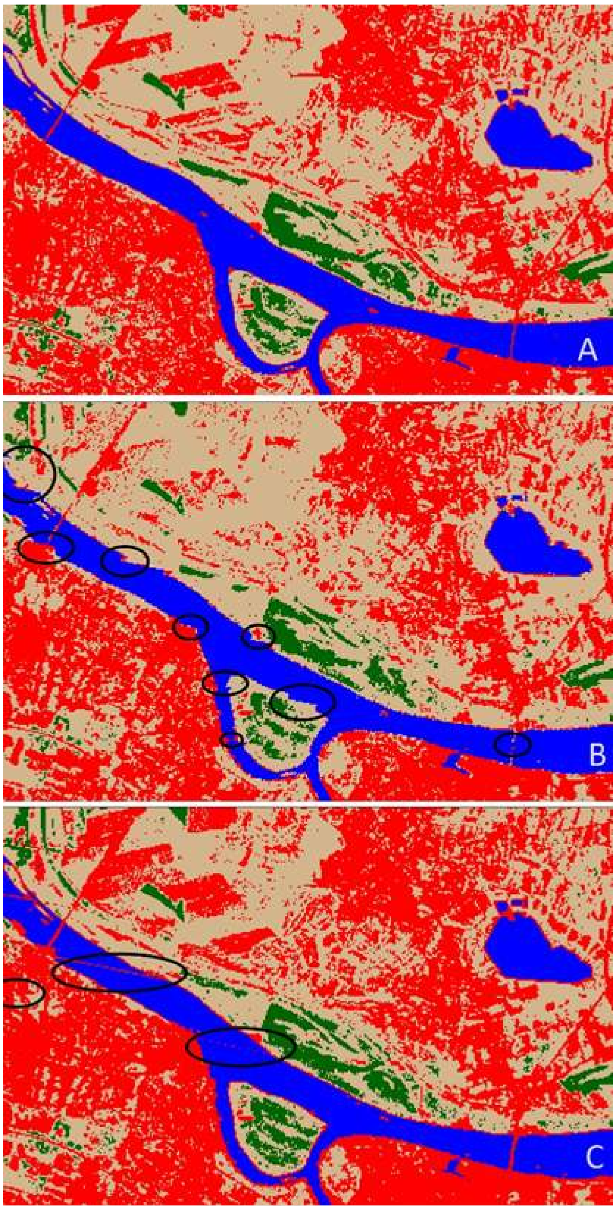

Figure 8. Supervised classification analysis. **A** Landsat 8 image **B** Landsat 7 Focal Analysis gap fill method **C** Landsat 7 LLHM gap fill method. Ellipsoids represent disrupted areas

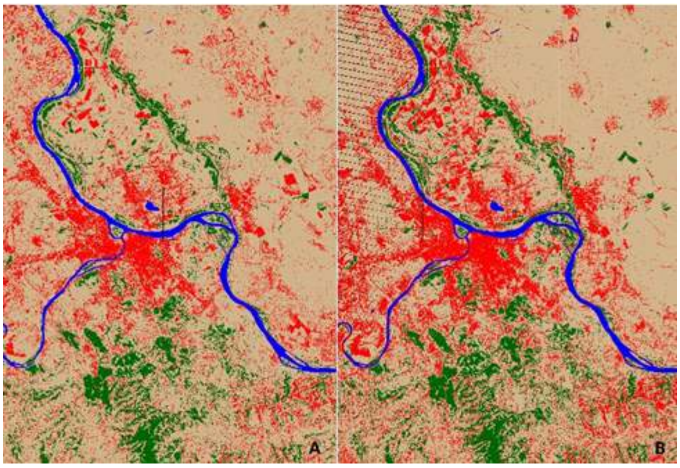

Figure 9. Supervised classification. **A** Focal analysis gap fill method **B** LLHM gap fill method

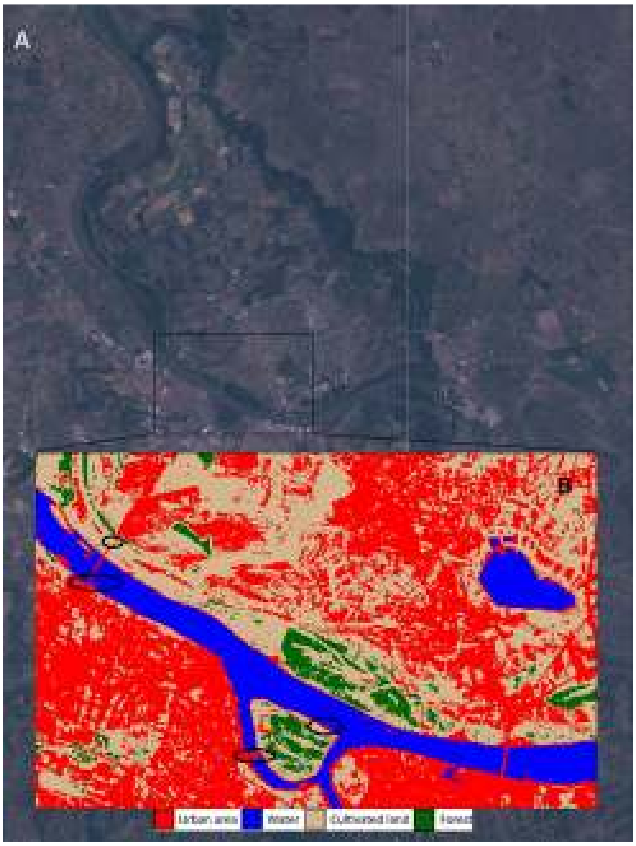

Figure 10. LLHM method applied to Landsat 7 SLC on image (June 2002) and SLC off image (June 2015). **A** Color composite **B** Supervised classification image

4. CONCLUSION

Nevertheless the Focal Analysis data looks better in color composite image, data acquired using LLHM method gives better result in Maximum likelihood supervised classification compared to data acquired from Landsat 8 data. Focal Analysis method should be used only for display purposes, as aesthetic image, and no analysis should be performed using that data. LLHM data, despite the non-filled gap area displayed, is more precise compared to Landsat 8 data. Fully filled gaps can be achieved using SLC-On image (acquired prior to May 31, 2003), another SLC-Off image with no overlapping gaps or using TM image [2].Unfortunately, the result obtained in this paper was not satisfactory.

Additional analysis was performed in order to examine the assertion using the SLC-On image. Obtained results were not as expected, since there was vast data disturbance.

New approaches using different geostatic methods were developed, such as ordinary kriging and co-kriging techniques. These techniques were employed to fill the data gaps and geo statistical methods can provide the uncertainty of predictions, which is a significant difference with the deterministic methods [7].

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