

Evaluation of Wavelet Fusion Method On Land Cover Classification In Bodetabek Area, Indonesia

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Abstract— This paper aims to present an evaluation of wavelet fusion method on land cover classification task. Wavelet fusion is one of the pan-sharpening methods which combines the higher spatial resolution panchromatic image with the lower resolution multispectral image to create high resolution fused image. Data fusion using multispectral and high spatial resolution panchromatic images are useful for improving classification accuracy. The study area of our research is Bodetabek (Bogor, Depok, Tangerang, and Bekasi) area, Indonesia. Different wavelet bases (Haar, Db2 to Db6, Coif1 to Coif5, and Sym1 to Sym5) were examined to determine the best basis for the data fusion process. This study also examined the effect of wavelet decomposition level to the spatial and spectral quality of the fused image. The experimental results on LANDSAT data show that the best basis for wavelet fusion is Coif5. The classification accuracy assessment on different wavelet decomposition level fused image also demonstrates that the higher wavelet decomposition, the higher spatial quality of the fused image. Although the spectral quality was degraded as the wavelet decomposition level increased, the classification accuracy assessment results show that higher wavelet decomposition level yields better overall classification accuracy (96.28% for eight decomposition level vs 82.77% for two decomposition level).

Keywords— LANDSAT, Pan-sharpening, Wavelet Fusion, Land cover Classification.

I. INTRODUCTION

One of the logical consequences of economic growth is city development. Every city must have a master plan for its land use. Indonesia has a city master plan called “Rencana Tata Ruang dan Wilayah Kota” for regulating the urban land use. It regulates all aspects of urban land use, from the planning to monitoring urban land use. Unfortunately, there are some cases where the local authority fails to implement this regulation in the field. One of the main causes is the urban sprawl. Urban sprawl could cause the regulator fail to keep the city development in line with the master plan. Bodetabek (Bogor, Depok, Tangerang, and Bekasi) area as the satellite city of Jakarta, the capital city of Indonesia, plays a strategic role in Jakarta development. According to Statistical Bureau of Indonesia, the area of Bodetabek is 5,736 square Kilometer. It is not an easy task to monitor city development in such large area. The lack of land use monitoring in Bodetabek area has

raised some problems in Jakarta, such as environmental degradation, garbage accumulation, flooding, and improper land use.

Remote sensing technology provides an effective way to monitor land cover change in the earth surface. The use of remote sensing technology on land cover change monitoring is more efficient than land survey technique, especially in a vast area. The launch of the first generation of earth observing satellite LANDSAT more than 40 years ago shows its potential on long term spatiotemporal analysis of earth surface. Spatiotemporal analysis of remotely sensed imagery combines spatial and temporal analysis of a certain area in the earth surface. Analysis of spatiotemporal data is useful for visualizing changes over time or deriving statistics from the data. Spatiotemporal analysis of the urban area provides valuable information on land cover change monitoring. Every change in the monitored area can be quantified and analyzed to check whether the change conforms to the master plan or not so that the decision maker can take required action whenever the change is not accordance with the plan.

A multispectral image of LANDSAT has a spatial resolution 30 m, while its thermal infrared image has a lower spatial resolution, which is 60 m. The spatial resolution of LANDSAT multispectral image is not enough for detail land cover change analysis since it couldn't see an object with size less than 30 x 30 m on the earth surface. Any road or river which is less than 30 meters wide will not be shown in the multispectral image. Starting from LANDSAT 7, NASA adds a panchromatic band that can capture higher spatial resolution (15 m) than its multispectral band. The panchromatic band of LANDSAT 7 combines green, blue, and near infrared wavelength into one band so that it can see more light at once. The multispectral bands can be combined with the panchromatic band to get a higher spatial resolution of the multispectral image; the technique is called pan-sharpening. Pan-sharpening is a data fusion process, whose goal is to enhance the spatial resolution of the multispectral images by including the spatial details contained in the panchromatic image [1]. After the pan sharpening applied to the multispectral image, it will have the same spatial resolution as the panchromatic image. There are several benefits in using pan sharpening i.e. wider spatial and

temporal coverage, decreased uncertainty, improved reliability, and increased the robustness of system performance [2].

In the past few years, there have been proposed several pan sharpening techniques, such as intensity hue saturation-(IHS), Brovey transform (BT), principal component analysis (PCA) and wavelet. The IHS and BT techniques only work on the red, green, and blue channel, while PCA and wavelet techniques can be applied to all multispectral channels. The wavelet image fusion technique can improve the spatial resolution and preserve the spectral characteristics at a maximum degree [2]. Wavelet fusion techniques could achieve better results than IHS, BT, or PCA schemes. The objective of this study is to evaluate the wavelet fusion method on the land cover classification of pan-sharpened LANDSAT multispectral images in Bodetabek Area, Indonesia. This work is a part of the research on the land cover change monitoring analysis on Bodetabek Area. We are going to analyze the land use of Bodetabek area and compare it with the “Rencana Tata Ruang dan Wilayah Kota” or urban land use plan. This paper will also discuss the optimal parameters of the wavelet fusion technique such as wavelet basis and decomposition level on the LANDSAT multispectral pan sharpening.

II. METHODOLOGY

A. Study Area and Data

Bodetabek area is located in Java island, Indonesia. The area bounded by $106^{\circ}20'44.27''$ E to $107^{\circ}17'50.45''$ E and $5^{\circ}54'50.78''$ S to $6^{\circ}47'5.76''$ S as shown in fig. 1. Bodetabek is also called as the satellite city of Jakarta, the capital city of Indonesia due its location surrounding the city. Two scenes of LANDSAT 7 data acquired on September 14, 2000, were obtained from USGS EarthExplorer. The first scene is located on path 122 row 64, while the second scene is on path 122 row 65 in World Reference System-2 (WRS-2) coordinate. The obtained LANDSAT data is level 1 terrain corrected or L1T product. The data were pre-georeferenced to UTM zone 48 North using WGS-84 datum. The other necessary corrections were performed in this study as explained in the next section.

B. Reference Data

Training and validation data were obtained to support classification model development. Training data were acquired from the land cover map of Badan Informasi Geospasial – BIG (Geospatial Information Agency), Republic of Indonesia (<http://www.bakosurtanal.go.id>). The map describes land cover as ESRI shape file for each class. There are four macro classes defined in the map i.e. settlement, agriculture, non-agriculture, and aquatic. Each class consists of several subclasses, but in this study, we focused on the macro class. Fig. 2 shows the land cover map from BIG, where red represents settlement area, green represents agriculture area, light green represents non-agriculture area, and blue represents aquatic area.

C. Preprocessing

There are several preprocessing steps applied to the LANDSAT data before the pan sharpening and classification

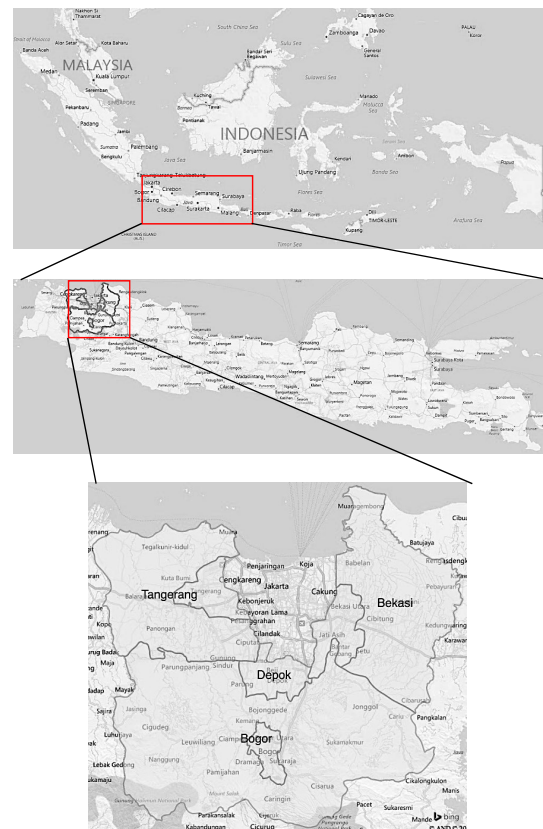


Figure 1. Study area

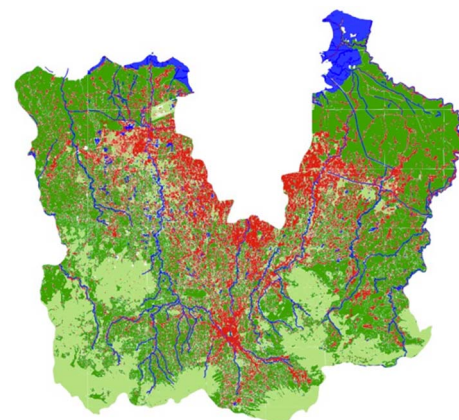


Figure 2. Study area

steps carried out. The preprocessing steps are mosaicking, crop the region of interest (ROI), and radiometric correction.

1) Mosaicking

Since the study area is spanned over two LANDSAT scenes i.e. path 122 row 64 and path 122 row 65 in the WRS-2 coordinate system, these scenes should be merged into one image. Fig. 3 shows the result of the mosaicking step. The red polygon defines the borderline of Bodetabek area.

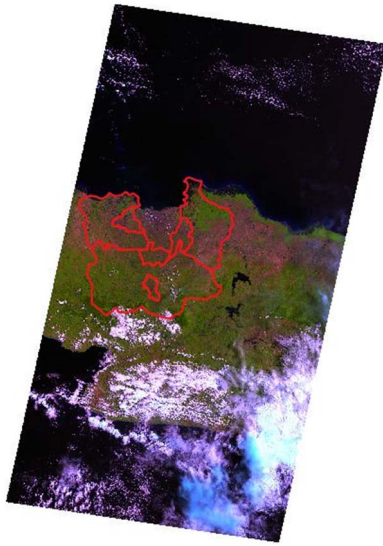


Figure 4. Mosaicking result

2) Crop the ROI

The region of interest area in this study is the Bodetabek area. Cropping ROI select Bodetabek area from the merged image (the area inside the red polygon in fig. 3). As can be seen in fig. 2, although the percentage of cloud cover in the image is quite high, but they are located outside our study area. Only small portion of the study area affected by the cloud. The multispectral images dimension after cropping applied is 3,255 rows x 3,614 columns, while the panchromatic image is 6,510 rows x 7,288 pixels.

3) Radiometric Correction

There are two types of radiometric corrections, absolute correction, and relative correction, are generally used to normalize remotely sensed images for spatiotemporal analysis. Absolute radiometric correction is aimed towards extracting the absolute reflectance of scene targets at the surface of the earth. Generally, absolute radiometric correction is a two-step process. The first step is the conversion of the digital number (DN) from the sensor measurements to the spectral radiance measured by the satellite sensor using the following equation [3]:

$$L_{\lambda} = \left(\frac{LMAX_{\lambda} - LMIN_{\lambda}}{QCALMAX - QCALMIN} \right) * (QCAL - QCALMIN)$$

where,

QCAL = digital number
 LMIN $_{\lambda}$ = spectral radiance scales to QCALMIN
 LMAX $_{\lambda}$ = spectral radiance scales to QCALMAX
 QCALMIN = the minimum quantized calibrated pixel (typically = 1)
 QCALMAX = the maximum quantized calibrated pixel value (typically = 255)

The second step of absolute radiometric correction is to convert the sensor detected radiance into ground surface reflectance using the equation:

$$\rho_{\lambda} = \pi * L_{\lambda} * \frac{d^2}{ESUN_{\lambda}} * \cos\theta_s$$

where,

ρ_{λ} = Unitless planetary reflectance
 L $_{\lambda}$ = spectral radiance (from earlier step)
 d = Earth-Sun distance in astronomical units
 ESUN $_{\lambda}$ = mean solar exoatmospheric irradiances
 θ_s = solar zenith angle

D. Wavelet Fusion

Most pan sharpening methods in the literature follow the following operations [1]:

1. Extract geometrical details of the scene from the PAN image (spatial information) that are not available in the multispectral image.
2. Combine the spatial information with the lower resolution multispectral image by interpolation operation to meet the size of PAN image by properly modeling the relationship between the multispectral and PAN images.

Wavelet transform showed its potential to the image fusion domain in the recent years due to its multi-resolution analysis feature. Standard wavelet-based image fusion performed by decomposing two input images separately into approximation and detail coefficients. The high-frequency parts of the multispectral image are replaced by the detail coefficients of PAN image. The combination the spatial information from PAN image with the multispectral images is performed at this step. The PAN sharpened image obtained by transforming the new wavelets coefficients with the inverse wavelet transform. Fig. 4 shows the scheme of wavelet fusion method.

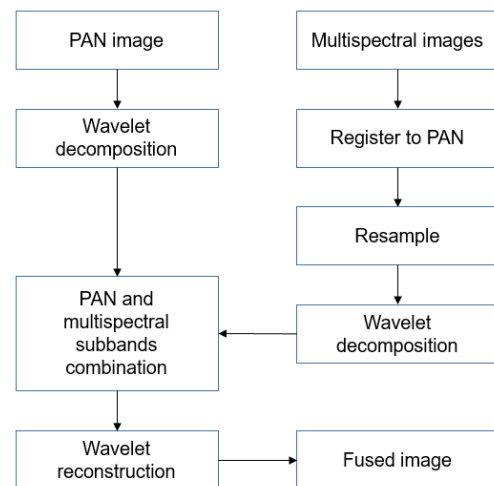


Figure 3. Wavelet fusion scheme

E. Spectral Angle Mapper

We used Spectral Angle Mapper (SAM) to compare the unknown pixel spectrum with the reference spectra from the ground truth data. SAM is a common strategy to measure the deterministic similarity between unknown pixel t spectrum with reference spectra, r_i , $i = 1, \dots, K$ of K references spectra and assigns t to the material having the closest distance:

$$\text{Class}(t) = \arg \min_{1 \leq i \leq K} d(t, r_i)$$

The reflectance spectra of an individual pixel can be represented as a vector in n -dimensional space, where n denotes the spectral band number. The length of the vector describes the brightness of the pixel, while the direction describes the spectral feature of the pixel. The length of the vector variation mainly caused by the change of illumination, while the vector angle variability corresponds to its different spectral variability [4]. The spectral angle is calculated by the following formula:

$$\theta = \cos^{-1} \left(\frac{\sum_{i=1}^n t_i r_i}{\sqrt{\sum_{i=1}^n t_i^2} \sqrt{\sum_{i=1}^n r_i^2}} \right)$$

where n denotes the number of spectral bands, t is the reflectance of the actual spectrum and r is the reflectance of the reference spectrum. The spectral angle can have values between 0 and $\pi/2$. The more similar pixels spectra, the smaller angle between them.

F. Image Quality Assessment

There are several ways to examine the result of pan sharpened image. The quality of the pan-sharpened image can be measured by its spatial and spectral quality. It is easy to judge the spatial quality by visual inspection to the high-frequency part of the image (sharp edges), but it is more difficult to judge spectral quality due to the limitation of the human eyes on matching the colors of the pan sharpened image with the original multispectral images. In this study, we used three metrics to examine the pan sharpened image quality i.e. spatial coefficient for spatial quality measurement, spectral angle mapper (SAM) for spectral distortion calculation, and relative dimensionless global error in synthesis (ERGAS) for both spatial and spectral quality measurements. The spatial coefficient measures the correlation between the high-frequency component of PAN image and pan-sharpened image. The reference value for the spatial coefficient is 1. The following convolution mask applied to extract the high-frequency component of the images:

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

SAM and ERGAS calculated by the equation (4) and (5). The reference value for SAM and ERGAS is 0.

$$\text{SAM: } \cos(\alpha) = \frac{\sum_{i=1}^n A_i B_i}{\sqrt{\sum_{i=1}^n A_i^2} \sqrt{\sum_{i=1}^n B_i^2}}$$

$$\text{ERGAS} = 100 \frac{h}{l} \sqrt{\frac{1}{n} \sum_{i=1}^n \left(\frac{\text{RMSE}(i)}{\mu(i)} \right)^2}$$

$$\text{RMSE} = \sqrt{\sum_{i=1}^d \sum_{j=1}^n \frac{(A_j(i) - B_j(i))^2}{r \times c \times n}}$$

where n is the number of bands, $A = (A_1, A_2, \dots, A_n)$ and $B = (B_1, B_2, \dots, B_n)$ are two spectral vectors with the same wavelength from the multispectral image and fused image, respectively. α is the spectral angle at a specific location. $d = r \times c$ is the number of the pixels in multispectral images [5].

III. RESULT AND DISCUSSION

A. Wavelet Fusion

To determine the optimal parameter for wavelet fusion, several wavelet bases (Haar, Daubechies 2 to Daubechies 6, Coiflet 1 to Coiflet 5, and Symlet 1 to Symlet 5) were applied in the experiments. Three spatial and spectral quality measurements e.g. spatial coefficient, SAM, and ERGAS were used to examine pan sharpened images as the output wavelet fusion process. Once the optimal wavelet basis determined, the number of decomposition levels were examined using the same three metrics.

Table 1 shows the evaluation result of wavelet fusion of different wavelet bases using two-level wavelet decomposition. According to the reference value of each quality measure, the best results are written in bold. The evaluation result in Table 1 shows that the more complex wavelet basis, the better spatial and spectral quality. The higher spatial coefficient shows higher correlation between the high-frequency component of PAN image and pan-sharpened image. The optimal SAM and ERGAS value is zero or near zero. As can be seen in the table, the SAM and ERGAS values are getting smaller as the wavelet basis more complex. From this evaluation, we can conclude that the best wavelet basis for the tested data is Coiflet 5.

The next evaluation is to determine the effect of decomposition level to the spatial and spectral quality of the fused image. The best wavelet basis from the previous experiment i.e. Coiflet 5 was used in the wavelet fusion process using different level of decompositions (3 to 8). Table 2 shows the result of the evaluation on different wavelet decomposition levels. As can be seen in table 2, the higher wavelet decomposition level applied the higher spatial coefficient. The opposite facts happened to the spectral quality measurements, SAM and ERGAS. Higher wavelet decomposition level cause degradation to the spectral quality (higher SAM and ERGAS value).

TABLE 1. WAVELET FUSION EVALUATION ON DIFFERENT WAVELET BASES

Wavelet basis	Spatial Coef.	SAM	ERGAS
haar	0.722	1.979	2.272
db2	0.864	1.888	2.202
coif1	0.874	1.926	2.248
sym1	0.722	1.979	2.272
db3	0.957	2.72	3.029
coif2	0.928	1.83	2.131
sym2	0.865	1.887	2.202
db4	0.926	1.857	2.163
coif3	0.936	1.808	2.098
sym3	0.912	1.918	2.211
db5	0.932	1.82	2.119
coif4	0.939	1.799	2.084
sym4	0.925	1.814	2.133
db6	0.935	1.823	2.098
coif5	0.939	1.796	2.076
sym5	0.930	1.808	2.094

TABLE 2. WAVELET FUSION EVALUATION ON DIFFERENT WAVELET DECOMPOSITION LEVELS

Decomposition Level	Spatial Coef.	SAM	ERGAS
3	0.968	2.682	2.959
4	0.972	3.493	3.774
5	0.973	4.203	4.449
6	0.974	4.929	5.052
7	0.975	5.706	5.550
8	0.976	6.432	5.998

Fig. 5 shows 2× zoomed version of a subset of the pan sharpened image of wavelet fusion using Coiflet5 as its basis. Fig. 5.a is the original multispectral image. Fig. 5.b is the result of wavelet fusion using 2 wavelet decomposition level, while Fig. 5.c shows the result of 8 wavelet decomposition level. As we can see in the figure, the fused image contains more detail than the original multispectral image. Higher wavelet decomposition level cause degradation on spectral quality, it showed as less color information in the fused image. The color degradation effect noticed clearly on orange rectangle object in the center of the image became gray in fig. 5.c.

B. Land Cover Classification

The results from the previous experiments have shown that the best wavelet basis for the wavelet fusion is Coif5 and the number of wavelet decomposition level affects the spatial and spectral quality of the fused image. The effect of wavelet decomposition level could be detected visually from the fused image but it is not clear whether it also has an effect to the classification accuracy in the land cover classification problem. To prepare the classification model, we chose a number of pixels from each class as the training data for SAM (134,893 pixels from settlement area, 121,780 pixels from aquatic area, 137,049 pixels from agriculture area and 132,780 pixels from non-agriculture area). The classification carried out twice times, the first on the 2 level wavelet decomposition fused image, another classification on the 8 level wavelet decomposition fused image. Fig. 6 shows the classification result compared to



(a)



(b)



(c)

Figure 5. Subset of (a) original multispectral image (b) fused image using: 2 wavelet decomposition level (c) 8 wavelet decomposition level

the land cover maps from BIG. Based on the visual inspection to the classification result, the classification on 2 level wavelet decomposition fused image gives a more similar map to the reference than the classification on 8 level wavelet decomposition fused image. The higher wavelet decomposition level causes the fused image became smoother.

Table 3 provides a comparison of accuracy assessment results between 2 wavelet decomposition level fused image (L2) and 8 wavelet decomposition level fused image (L8). The overall accuracy of L8 was significantly higher than L2, 82.77% vs. 96.28%. This result is contrast to the visual inspection of the classification result as shown in fig. 3. The best classification performance comes from the aquatic area, while the most difficult classification task was on settlement area. This result

concludes that higher wavelet decomposition level could improve classification accuracy although it also decreased the spectral quality at the same time. This experiments also demonstrates that wavelet fusion method is useful for the classification task of pan-sharpened image.

TABLE 3. FONT SIZES FOR PAPERS

Class	L2		L8	
	PA%	UA%	PA%	UA%
Settlement	76.94	92.24	98.68	99.32
Aquatic	96.19	82.47	99.77	98.26
Agriculture	76.78	82.84	94.70	93.86
Non-Agriculture	81.93	70.69	90.71	92.24
Overall accuracy	82.77%		96.28%	
Kappa statistic	0.78		0.95	

IV. CONCLUSIONS

This study discussed an evaluation of wavelet fusion pan sharpening on land cover classification task. The experimental results on LANDSAT data demonstrate that the best wavelet basis for wavelet fusion is Coiflet 5. The results also show that the more complex wavelet basis chosen, the better both spatial and spectral quality of the fused image. Although the spatial quality of the fused image was increased as the wavelet decomposition increased, the opposite fact happened to the spectral quality. The spectral quality of the fused image was degraded as the wavelet decomposition level increased. The classification accuracy assessment result on different wavelet decomposition fused image shows that the spectral quality degradation does not cause the classification accuracy decreased.

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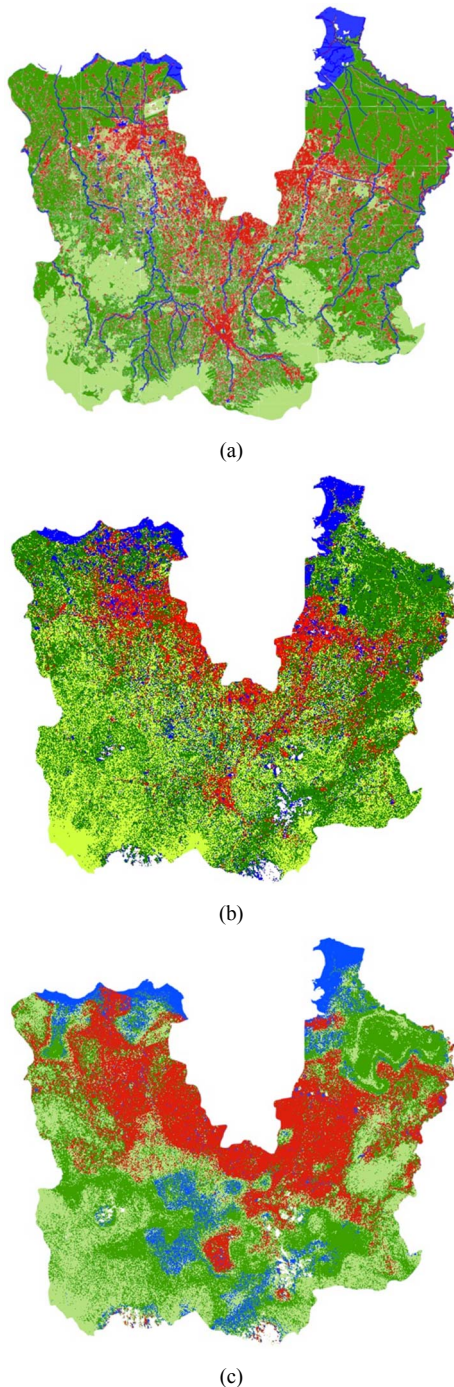


Figure 6. (a) land cover map from BIG; classification result of (b) 2 wavelet decomposition level (c) 8 wavelet decomposition level



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