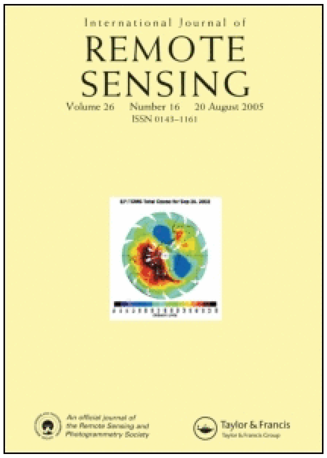

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Accuracy of land cover area estimated from coarse spatial resolution images using an unmixing method

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Technical Note

Accuracy of land cover area estimated from coarse spatial resolution images using an unmixing method

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Abstract. Many techniques intended to estimate land coverage of multiple categories occupied within each pixel from such coarse resolution data have been proposed. However, in traditional unmixing studies with coarse resolution imagery such as Advanced Very High Resolution Radiometer (AVHRR) data, it is assumed that only a few endmembers exist throughout an entire image. Therefore, it is essential to evaluate how well an unmixing method would work for various categories within pixels of coarse resolution images. In this study, the land coverage of eight classes in National Oceanic and Atmospheric Administration (NOAA) AVHRR imagery by using finer resolution Landsat Thematic Mapper (TM) imagery was estimated, and the accuracy of these estimated classes was evaluated. The results suggest that this method may be generally useful for comparing multi-spectral images in space and time.

1. Introduction

The utilization of coarse resolution images, which easily cover a wide area, can be considered. For example, the Advanced Very High Resolution Radiometer (AVHRR) has been utilized to study vegetation development cycles (Achard and Blasco 1990), perform land cover type classification (Tucker *et al*. 1985) on continental and global scales, and monitor vegetation transformations such as tropical deforestation (Nelson and Holben 1986). The AVHRR provides fine temporal solution of a given land target. Nevertheless, even though coarse resolution satellites can observe the Earth in a short period, many categories are intermingled within each pixel of the observed image. It is necessary to determine the categories and to calculate the land coverage of each with precision.

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There are several unmixing methods (Adams *et al.* 1986, Inamura 1988, Smith *et al.* 1990, Settle and Drake 1993, Huguenin *et al.* 1997, Settle and Campbell 1998) that allow a user to estimate the subpixel coverage within each category using linear mixture models. However, the spectral radiance (endmember) of each category covered within a pixel must be precisely known before carrying out the unmixing method (Cross *et al.* 1991, Quarmby *et al.* 1992, Foody and Cox 1994). Several methods have been proposed for estimating the endmembers for each category (Oleson *et al.* 1995, Tompkins *et al.* 1997, Bateson *et al.* 2000, Defries *et al.* 2000, Oki *et al.* 2002). For example, Oleson *et al.* (1995) and Oki *et al.* (2002) have retrieved spectral reflectance for each land cover type in coarse resolution imagery using fine spatial resolution imagery. However, in traditional unmixing studies with coarse resolution imagery such as AVHRR data, it is assumed that only few endmembers exist throughout an entire image (Defries *et al.* 2000, Robinson *et al.* 2000). Therefore, it is essential to evaluate how well an unmixing method would work for various categories within pixels of coarse resolution images such as AVHRR.

In this study, the land coverage of eight classes in AVHRR imagery by using higher resolution Landsat Thematic Mapper (TM) imagery was estimated, and the accuracy of the estimated classes was evaluated. The land coverage of three classes was also estimated.

2. Unmixing method for coarse spatial resolution image

Many recent studies have demonstrated the potential of linear mixture models (Adams *et al.* 1986, Inamura 1988, Smith *et al.* 1990, Settle and Drake 1993) wherein the spectral radiance varies linearly with the relative proportions of the categories within the subpixel mixtures of various land cover type. However, unless the spectral radiance (endmember) of a particular category is known, it is impossible to decompose these linear mixture models to calculate the category ratio within a mixed pixel. It is difficult to identify the spectral signature of pure components or endmembers which form the scene.

In this study, endmembers are estimated from coarse resolution images by overlapping a classified TM image over an AVHRR image based on a linear mixture model. In the AVHRR image, a linear spectral mixture model is a model where the observed radiance of a particular pixel is given as $\boldsymbol{P}$ by endmember $\boldsymbol{m}$ which represents each category when cover ratio a of k types of categories exist, as in the following equation:

$$\boldsymbol{P} = \sum_{j=1}^{k} a_j \boldsymbol{m}_j \tag{1}$$

where,

$$a_j \geqslant 0, \ \sum_{j=1}^{k} a_j = 1 \tag{2}$$

and

$$\boldsymbol{m}_j \geqslant 0 \tag{3}$$

If the endmember $\boldsymbol{m}$ is given, the unknown ratio of area within a pixel can be estimated from the observed radiance $\boldsymbol{P}$. However, in the actual image, it is difficult to determine the endmember $\boldsymbol{m}$ for each category.

In this study, a TM image, which overlaps part of the observed area from an AVHRR image, was used in order to calculate the endmember of each category of the AVHRR image. First, a TM image is used to geo-correct an AVHRR image. Next, we classify the TM image into k types of categories. Here, land coverage a of each pixel in the AVHRR image is calculated by overlapping land cover distribution, which is evaluated from the TM image, on to the AVHRR image. Furthermore, the endmember $\boldsymbol{m}$ of each category in the AVHRR image is estimated. In this study, under the condition of equation (3), a quadratic programming method (Inamura 1988) was used in order to estimate the unknown endmember $\boldsymbol{m}$ of each category in equation (1).

Using the estimated endmembers, the entire AVHRR image is unmixed. The land coverage a for each unknown category in equation (1) is estimated by unmixing the entire AVHRR image under the condition of equation (2).

Conventional unmixing methods assume that the number of endmembers are three or four in an entire scene, and attempt to find fractions for these endmembers in every pixel (Defries *et al.* 2000, Robinson *et al.* 2000). In this study, we have applied the proposed unmixing methodology by unmixing the AVHRR image into eight categories using multi-temporal AVHRR images. The land coverage of three classes was also estimated.

3. Processing of Landsat TM

In this study, we selected Siberia's wetland area as the study site. as shown in figure 1. In the study area, the land cover types have been investigated by the National Institute for Environmental Studies, Japan, and we made classification imagery with multi-temporal Landsat TM data as a high spatial resolution image based on the ground data. The multi-temporal TM image was classified into three and eight categories by the ISODATA method using two data (16 June and 18 July 1997) in order to improve the classification accuracy, especially the wetland area. The thermal infrared band (band 6) was not used in the classification. The eight

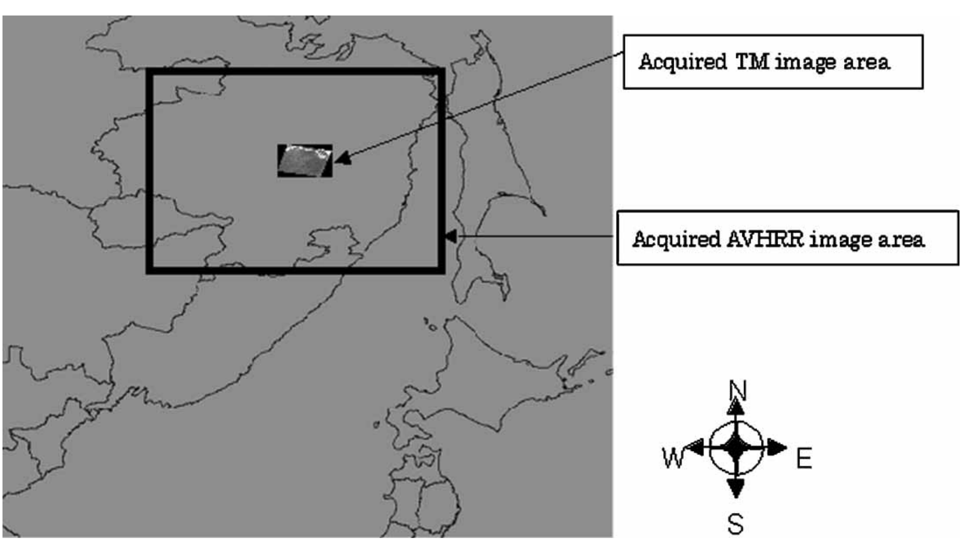

Figure 1. Location of the study site. (Upper left coordinate: 52°N, 121°E; lower right coordinate: 42°N, 142°E.)

categories were classified as wetland 1, wetland 2, grassland, evergreen, deciduous trees, agricultural area, urban area/bare soil and water, as shown in figure 2. Furthermore, figure 3 shows three classification (vegetation, urban area/bare soil and water) images that were created in order to compare with the eight category results. Table 1 shows the definitions for nomenclature used in this study. In figures 2 and 3, the left classified TM image is used to estimate the endmembers of an AVHRR image, and the right image is used to evaluate the accuracy of the unmixing method.

4. Processing of NOAA AVHHR

Figure 4 shows a multi-temporal National Oceanic and Atmospheric Administration (NOAA) AVHRR image dataset produced by combining three images from 13 June, 27 July and 1 September 1997 at the location shown in figure 1. In this study, all five bands for each image were used; thus, a 15 band dataset was produced. By using a multi-temporal image dataset (15 band images), it is possible to unmix the AVHRR image into three or eight categories. Then, cloud areas were removed in each image. In figure 4, the black colour expresses cloud and sea area.

In this study, each AVHRR image was corrected geometrically using TM images as a datum. A nearest neighbour interpolation method was used to prevent the original pixel values from being annulled. As a result, the error of superposed AVHRR image was less than 1.0 pixel.

5. Results and discussion

The endmembers of AVHHR images estimated from equation (1) using each land coverage calculated by overlapping classified TM imagery are shown in figure 5 and figure 6, respectively for eight categories and three categories. Furthermore, using the estimated endmembers, results of the AVHHR images unmixed from equation (1) under the condition of equation (2) are shown in figure 7 and figure 8, respectively, for eight categories and three categories.

In figures 7 and 8, the black colour expresses cloud and sea area, which were not used for analysis in this study. Using the rms error (RMSE) as shown in equation (4), the accuracy of this unmixing method was evaluated for both three categories and eight categories cases by comparing the results with the respective classified TM image made using the ground truth information, assuming that the classified image was true. RMSE is expressed as

$$\mathrm{RMSE}=\sqrt{\frac{\sum_{i=1}^{n}\left(\hat{a}_i-a_{ih}\right)^2}{n}} \tag{4}$$

where $\hat{a}$ is each land coverage of each pixel estimated by unmixing an AVHRR image, a_h is the true land coverage of each pixel in the AVHRR image calculated by overlapping land cover distribution, which is evaluated from the TM image, on to the AVHRR image, and n is number of pixels in the validation area of the AVHRR image. Results of the RMSE are shown in table 2 for eight categories and three categories.

Several conclusions can be drawn from these results. For both eight and three categories, although the unmixing accuracy was different according to land cover type, it was found that RMSE of each land cover was less than 50%. Therefore, it is

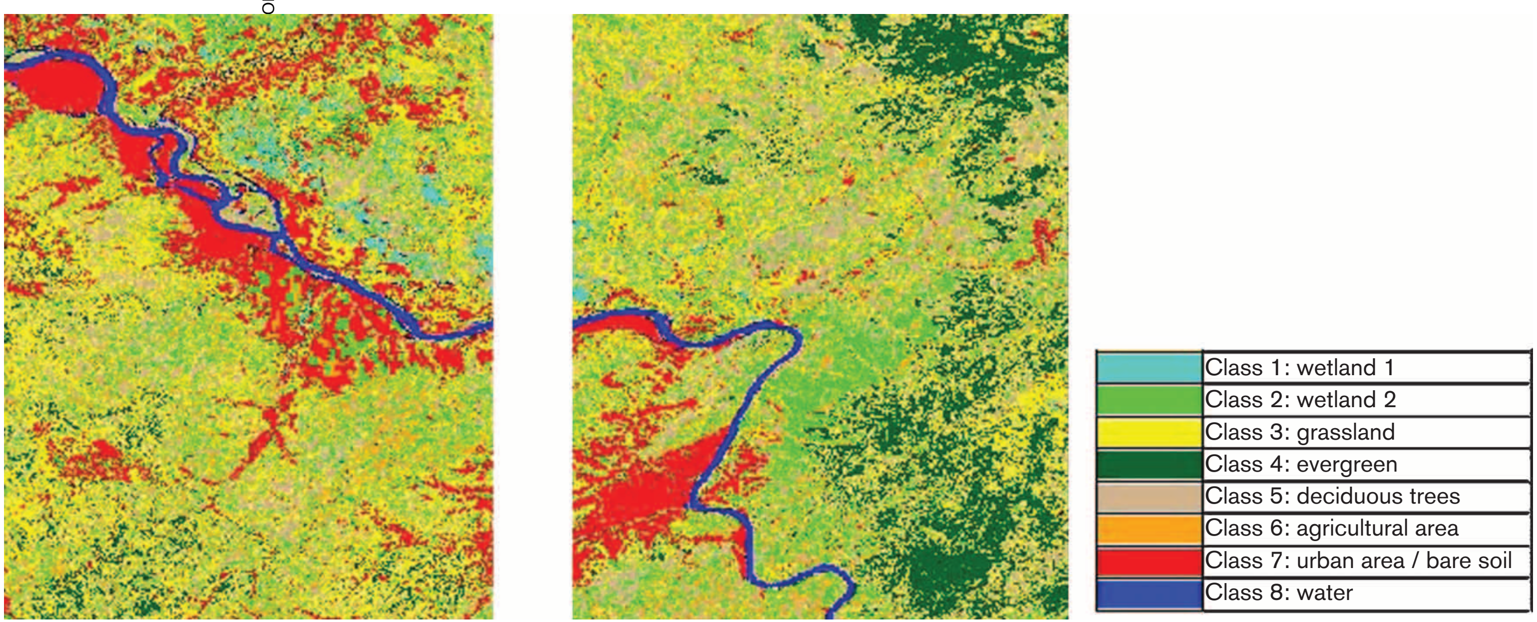

Figure 2. Eight classifications map using multitemporal Landsat TM imagery. (Path 116/row 26.)

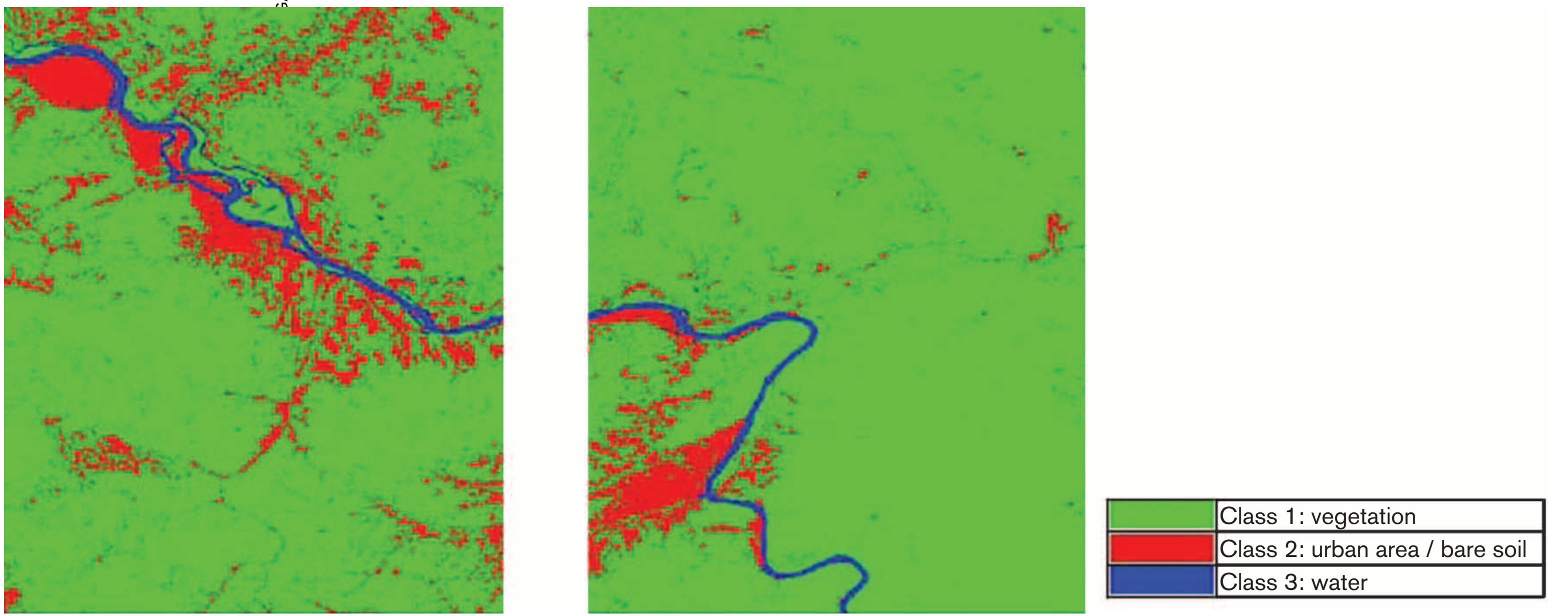

Figure 3. Three classifications map using multitemporal Landsat TM imagery. (Path 116/row 26.)

Table 1. Definitions of nomenclature used in this study.

Category No.	Category type	Description
Eight category		
1	wetland 1	reeds constitute this category; water level is high
2	wetland 2	sedges consitute this category; water level is low
3	grassland	grasses constitute this category; dry area
4	evergreen	evergreens constitute this category; dry area
5	deciduous trees	deciduous trees constitute this category; dry area
6	agricultural area	areas where agriculture is inactive
7	urban area/bare soil	buildings, roads, areas where agriculture is inactive
8	water	rivers, lakes and sea
Three category		
1	vegetation	wetlands, forests, agricultural areas constitute this area
2	urban area/bare soil	buildings, roads, areas where agriculture is inactive
3	water	rivers, lakes and sea

possible to quantitatively estimate each land cover area within a pixel by the proposed method.

For eight categories, wetland 1 and water were estimated with relatively good accuracy. The RMSE for wetland 1 was 13.3%, and for water was 16.4%. Thus, it was shown that if the subject of one's research were reed or water they could be estimated from coarse resolution images with good accuracy. Traditionally, only approximate vegetations could be distinguished through coarse resolution images; however, by using the unmixing method in this study, the analysis of certain vegetation types, such as reeds, in an extensive area became easier.

Because the unmixing accuracy was relatively good for the three categories case, similarly it was possible to evaluate the land cover changes from the AVHRR

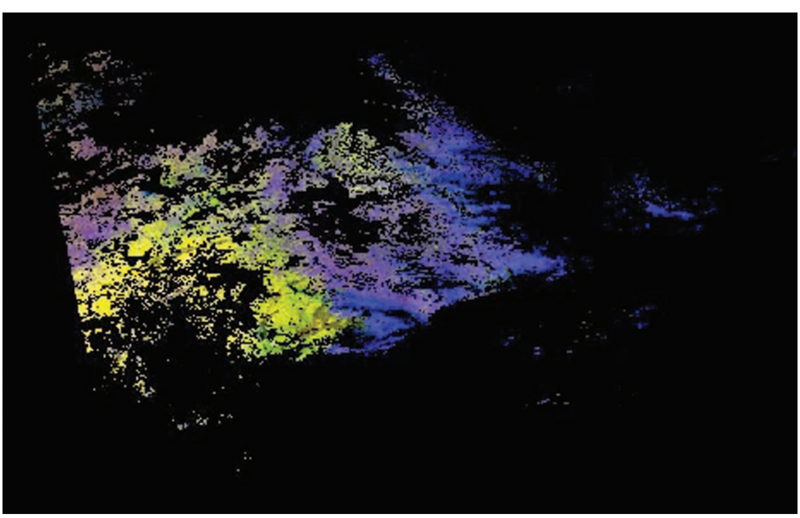

Figure 4. Multi-temporal AVHRR image data produced by combining three images from 13 June, 27 July and 1 September 1997. (Upper left coordinate: 52°N, 121°E; lower right coordinate: 42°N, 142°E.)

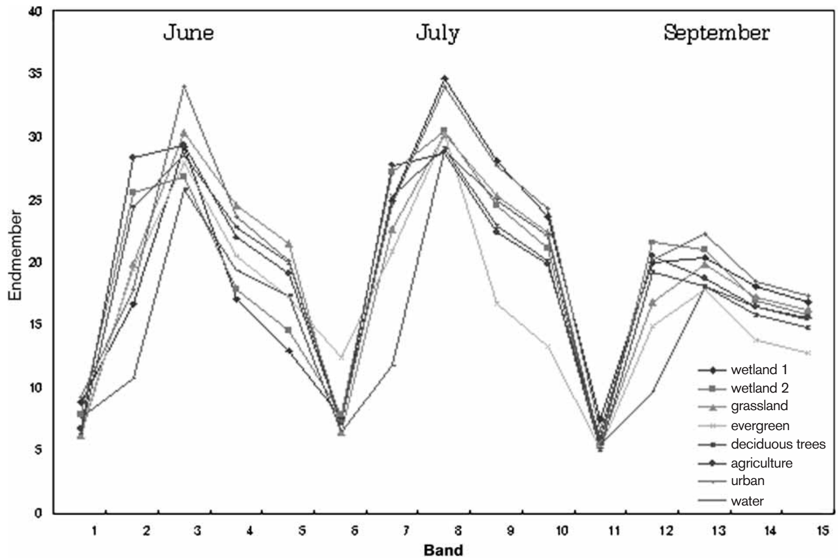

Figure 5. Estimated endmembers of AVHHR images for eight categories.

image. The conventional method for evaluating vegetation was to calculate NDVI (Normalized Difference Vegetation Index) from the AVHRR image (Elmore *et al.* 2000). However, this left the problem that only a relative amount of vegetation could be known. For this reason, it is advantageous that this technique can quantitatively estimate the area of each category.

The unmixing error exceeded 30% for some categories. The following points were considered as an explanation.

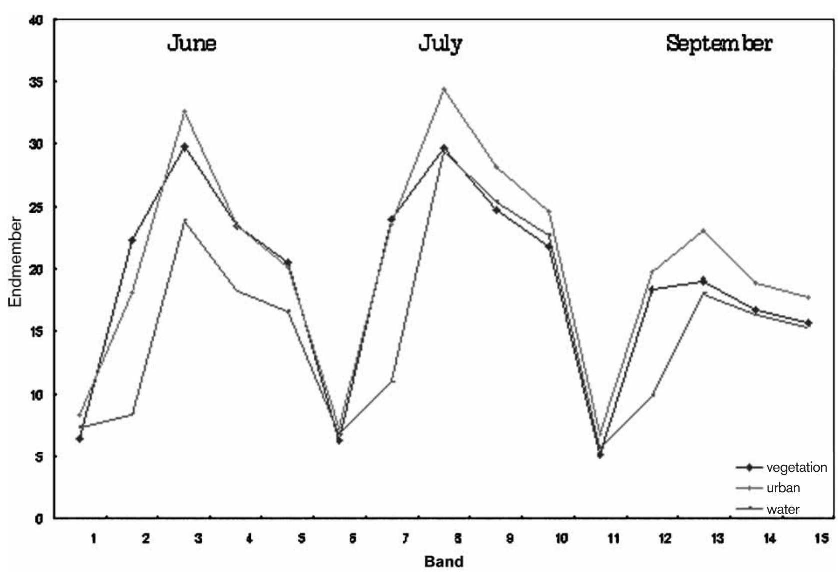

Figure 6. Estimated endmembers of AVHHR images for three categories.

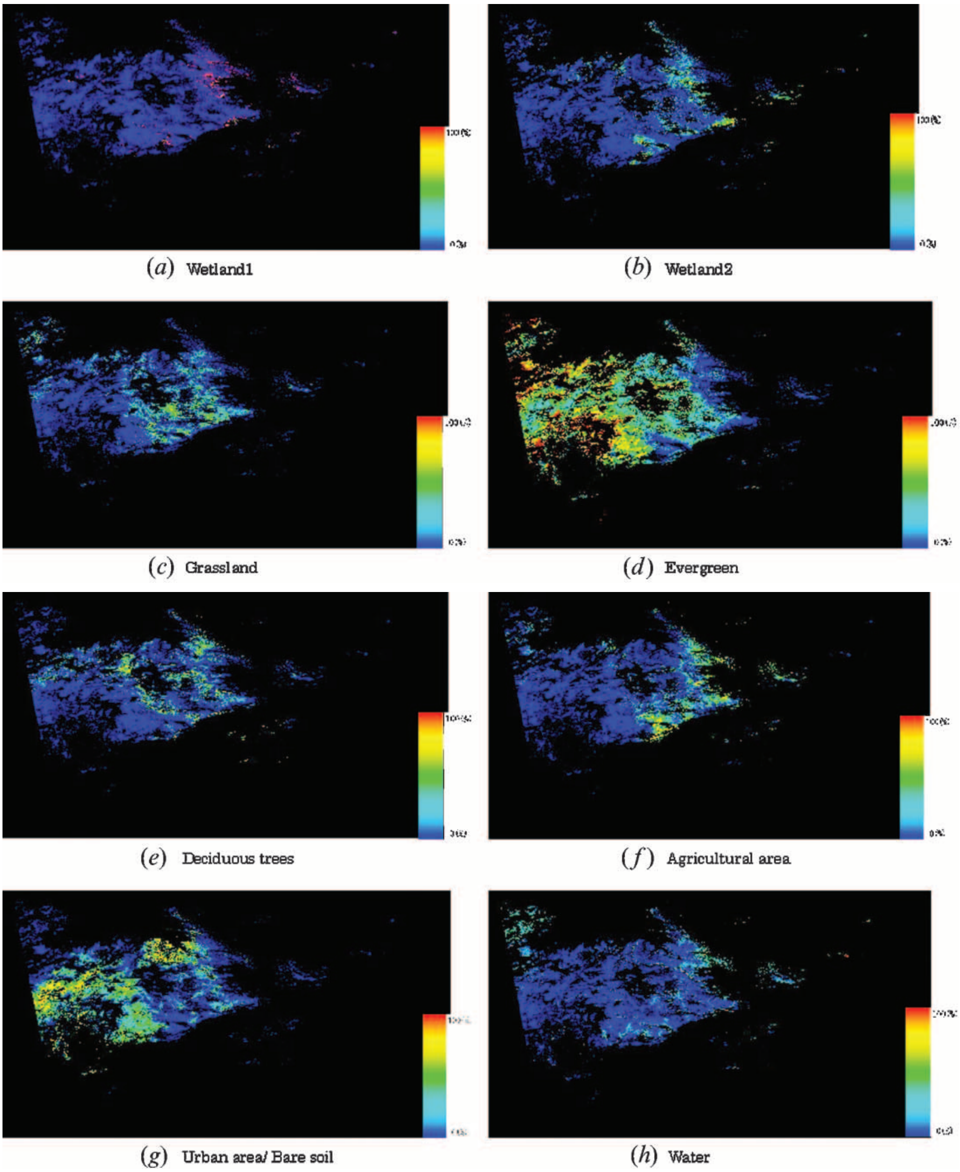

Figure 7. Distribution of each land coverage estimated by unmixing method.

(1) The spectrum values of each vegetation type resembled each other well, so it was difficult to discriminate each type and estimate endmembers.

(2) The classified image, which is assumed to be composed of pure pixels, always includes errors. So, the unmixing error of AVHRR image depends on the error of the classified TM image.

(3) Moreover, there was the problem of error caused by the geometric correction of the AVHHR imagery. The conversion error was less than 1.0 pixel. Due to this deviation caused by geometric correction, it is difficult to estimate an accurate endmember.

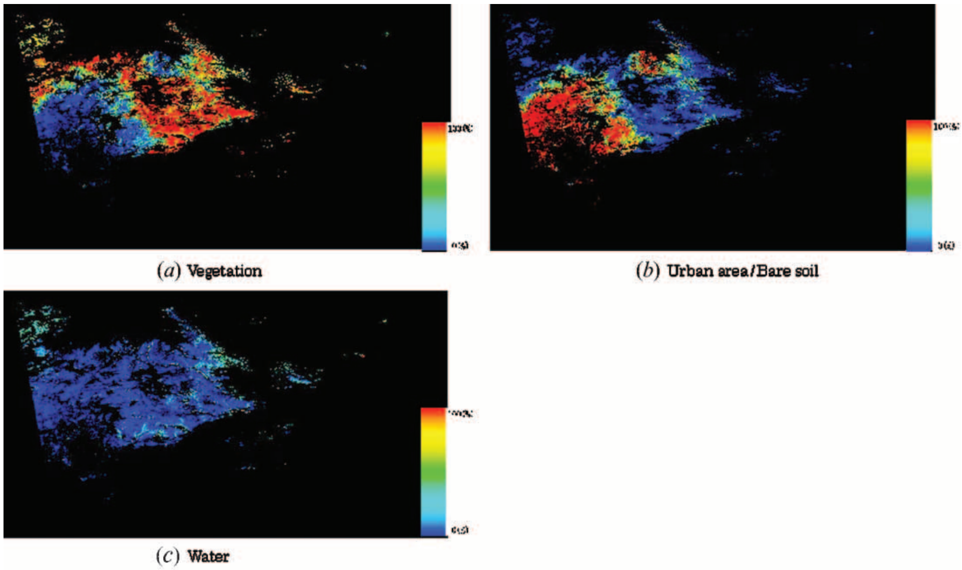

Figure 8. Distribution of each land coverage estimated by unmixing method.

Table 2. RMSE of unmixed AVHRR image for eight categories and three categories.

Eight category	RMSE (%)	Three category	RMSE (%)
Wetland 1	13.3	Vegetation	20.5
Wetland 2	25.2	Urban area/bare soil	17.3
Grassland	26.6	Water	15.7
Evergreen	19.6		
Deciduous trees	36.9		
Agricultural area	36.7		
Urban area/bare soil	18.5		
Water	16.4		

6. Conclusions

A practical unmixing method for mixed pixels of coarse resolution images has been proposed. This method utilized high-resolution images, such as Landsat TM images, in order to determine endmembers for mixed pixels in coarse resolution images, such as NOAA AVHHR images.

Furthermore, the evaluation of the unmixing accuracy was carried out when there are various categories of interest in coarse spatial resolution imagery. From the RMSE results, it was shown that the land coverage could be estimated with a relatively good accuracy. Although the unmixing accuracy was different according to land cover type, it was found that RMSE of each land cover was less than 50%. Therefore, it was possible to quantitatively estimate each land cover area within a pixel with the proposed method.

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