Monitoring of Long-term Urban Expansion by the use of Remote Sensing Images from Different Sensors

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ABSTRACT:
Rapid urbanization and industrialization have caused not only social problems but also environmental problems in most of the Asian mega-cities. History of land-cover changes and infrastructure changes due to urban expansion is one of the essential data to assess and predict the urban risk and environment in the future. Monitoring of urban expansion is, however, not easy because of the lack of information in the past. Remote sensing may provide us with an efficient tool to monitor land-cover changes in and around urban areas during past thirty years. With time series satellite data we may detect long-term changes. The long-term monitoring of land-cover, however, requires using different types of sensors since the mission life of satellite sensors is at most five years. Different sensors have different spectral and spatial characteristics, and direct comparison of spectral signatures may not give us correct information on land-cover changes. The objective of this paper is to investigate long-term land-cover changes with remote sensing data from different sensors. In order to detect land-cover changes from different sensors, a new method was devised which does not compare the spectral signature directly but compare the land-cover category-mixing ratio in each pixel derived from different sensors. Linear mixture model was used in this study to estimate category-mixing ratio. The method was applied to the city of Bangkok as a case study, and the long-term changes in and around the same were evaluated with LANDSAT TM and ETM+ during the period of ten years.

1 INTRODUCTION

For recent decades, rapid urbanization and industrialization have caused not only social problems but also environmental problems in most of the Asian mega-cities, such as urban heat island, water / air pollution, torrential rainfall, and so on. History of land-cover changes and infrastructure changes due to urban expansion is one of the essential data to assess and predict the urban risk and environment in the future. However, in many cases, monitoring of urban expansion is not easy because of the lack of information of past times. Existing historical land-use maps, if available, may neither cover whole target areas nor have accurate information and unique classification scheme. Remote sensing may provide us with an efficient tool to monitor land-cover changes in and around urban areas during the past thirty years since remote sensing data become available. With time series satellite data we may detect long-term urban changes. The long-term monitoring of land-cover, normally, requires using different types of sensor since the mission life of one sensor is at most five years. Different sensors have different spectral and spatial characteristics, and direct comparison of spectral signatures may not give us accurate information on land-cover changes.

The objective of this research is to investigate long-term land-cover changes with remote sensing data from different sensors. In order to detect land-cover changes over time from different sensors, a new method is applied which does not compare the spectral signature directly but compare the land-cover category-mixing ratio in each pixel derived from different sensors. Linear mixture model was used in this study to estimate category-mixing ratio. This method is based on VSW index proposed by Yamagata, et al. (1997), and successfully applied to monitor long-term urban growing in Tokyo (Sone, 2001).

2 METHODOLOGY

2.1 Study Area

The study area is located between 99º 52' - 100º 58' E and 13º 27' - 14º 17' N, and covering whole of Bangkok Metropolitan Region (BMR), Thailand (Figure 1). As a prime city of Thailand with a population of 10 millions, Bangkok city has rapidly urbanized and industrialized. The area in the low Chao Phraya delta with the dominance of rice cultivation 20 years before has been changed steadily to other land-uses such as urban and industrial areas, fruit-trees, vegetables, plantation, and shrimp farms. Rapid land-use change associated with imbalanced growth pattern in the area not only gives rise to serious social problems but also creates various environmental problems such as air / water pollution, urban heat island, land subsidence flooding, and so on (Tran and Yasuoka, 2000).

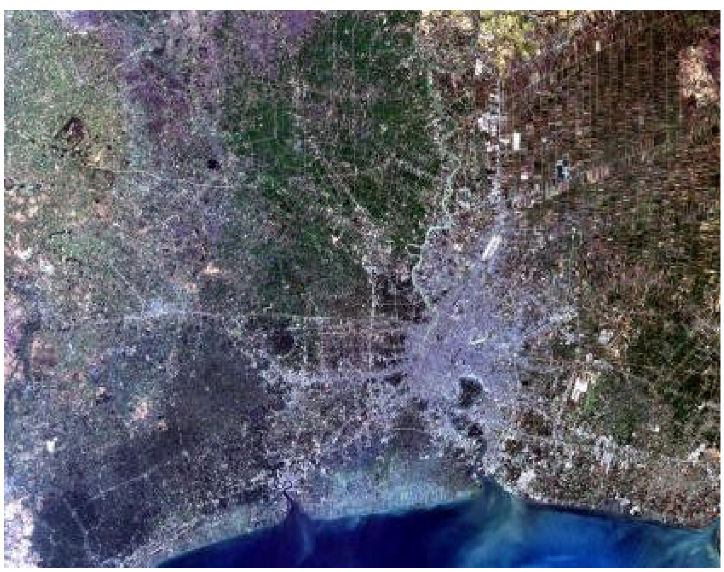

Figure 1 Study area (LANDSAT ETM+ true color image acquired on Jan. 8, 2002).

2.2 Data Used

Satellite images LANDSAT and ASTER during 1985 – 2002 were obtained for the study area to monitor long-term long-cover change. As sample data, cloud-free LANDSAT TM images acquired on December 25, 1993 and ETM+ images acquired on January 08, 2002 were used in this paper. As the acquisition dates of images differ within two weeks from each other, seasonal variation could be ignored. The study area is covered by mosaic of two scenes (path 129 / row 50 and path 129 / row 51) for each date. In addition, ancillary data such as topographic maps 1:50000 and existing land-use maps were also obtained for the analysis and result validation.

2.3 Pre-processing

LANDSAT images were corrected for atmosphere attenuation and geo-referenced to common base maps. In total 75 GCPs (ground control points) were selected on both images and used for geometric correction. Images were resampled to 30m resolution using nearest neighbor interpolation with RMS (root mean square) error of 0.731. Then, the original numbers of LANDSAT images were converted to radiance, in order to apply linear mixture model of different dates.

2.4 Calculation of VSW Index Using Linear Mixture Model

When comparing satellite images that catch same objects acquired from different sensors, characteristics of sensors such as spectral and spatial characteristics must be considered because same objects are observed in different ways by different sensors. In this sense, direct comparison of spectral signatures may not give us correct information on land-cover changes.

In this study, VSW (Vegetation-Soil-Water) indices which were proposed by Yamagata, et al. (1997) were used as land-cover category-mixing ratio in each pixel for single date image and the compared between 1993 and 2002 images to detect land-cover change. The VSW index evaluates the composition of 3 basic elements: vegetation, soil and water in each pixel. Its definition is shown in Figure 2, which shows relationship between VSW indices and the end member triangle on a NIR-RED scatter plot (in case of TM and ETM+, the red band is band 3 [0.63– 0.69 ìm], and the near infrared one is band 4 [0.75 – 0.90 ìm]). By spectral characteristics, each vertex of the triangle can be regarded as the end member point of the spectrum of vegetation, soil, and water. If P is the observed point, the length of PV, PS, and PW are defined as V, S, and W indices. These values indicate the composition of vegetation, soil, and water in each pixel.

One problem, however, comes up on how to chose the spectral point of end members. Picking up spectral points of end member by visual observation of an image depends on the subjectivity of observer. So in this study, an algorithm was applied to fit a triangle to the spectral meaning that vertices of the triangle including most of observed spectral points on the scatter plot are picked up automatically. This algorithm determines the triangle including more than 95% of observed spectral points on the scatter plot.

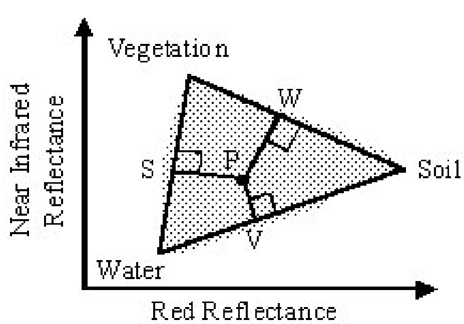

Figure 2 Relationships between VSW index and end member triangle on NIR-RED scatter plot.

Results of calculating VSW indices from satellite images TM images of 1993 and ETM+ images of 2002 are shown in Figure 3, which were used to detect the urban expansion.

2.5 Detect the Change to Urban Area with VSW Index

Since VSW index can evaluate the category-mixing ratio of three elements: vegetation, soil, and water in each pixel, it can be used to detect the land-cover change between images of different sensors. Based on nature of VSW indices and characteristics of the area, 6 main land-cover categories were considered: built up, dry bare soil, dry dense vegetation, irrigated dense vegetation, wet soil, and water.

In order to detect new urban area between 1993 and 2002 in study area, change pixels were firstly delineated using VSW indices. Here a concept of change vector in VSW space was adopted and Euclidean distance (*d*) between same observed points in 1993 and 2002 as shown in equation (1) was calculated for each pixel. Based on the statistics of the change image a threshold value was selected (*d* > 40) to delineate change pixels.

$$d = \sqrt{(V_{1993} - V_{2002})^2 + (S_{1993} - S_{2002})^2 + (W_{1993} - W_{2002})^2} \quad (1)$$

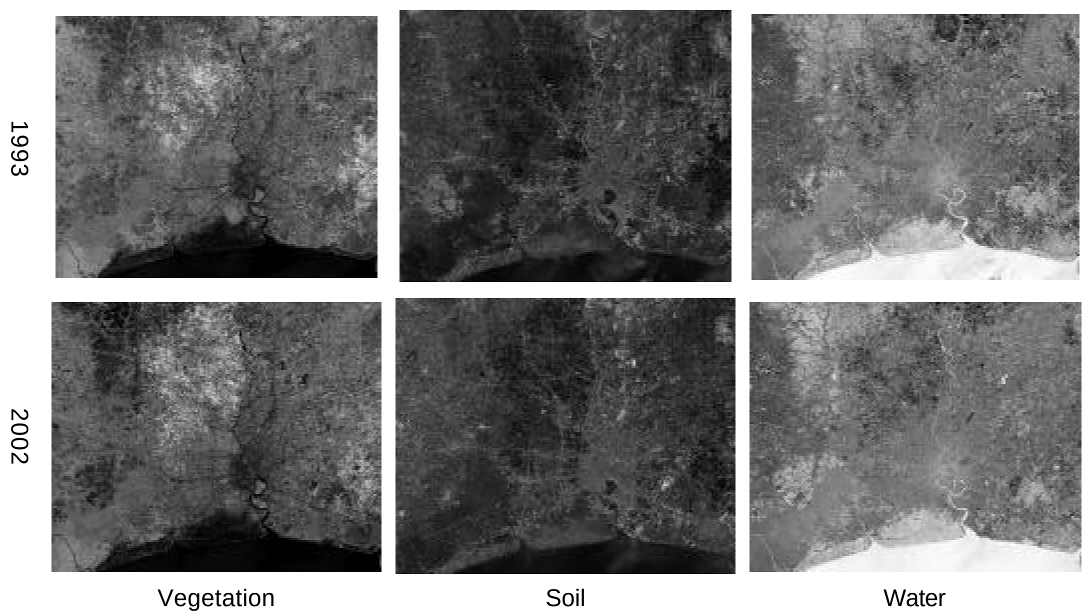

Figure 3 Distributions of VSW index.

Table 1 Means and standard deviations of VSW index in each land-cover category chosen as sample area.

Land-cover		1993		2002	
		Mean	Std. Dev.	Mean	Std. Dev.
Built Up Area	V	18.87	5.25	3.22	4.20
	S	80.61	14.04	89.19	11.28
	W	4.14	7.45	7.26	8.93
Dry Bare Soil	V	32.67	2.62	27.90	2.94
	S	55.29	5.43	61.29	7.94
	W	10.98	6.16	9.34	7.17
Dry Dense Vegetation	V	72.71	11.93	87.79	7.93
	S	10.50	8.75	3.61	2.31
	W	15.40	10.52	7.42	6.44
Irrigated Dense Vegetation	V	39.25	3.54	49.55	9.56
	S	5.89	2.44	5.37	3.16
	W	53.34	3.22	43.51	8.08
Wet Soil	V	16.04	4.29	15.38	2.76
	S	23.78	4.04	25.42	4.20
	W	57.80	6.51	57.71	5.62
Water	V	0.16	0.73	0.01	0.14
	S	43.41	13.86	36.98	8.48
	W	63.73	8.24	69.47	5.25

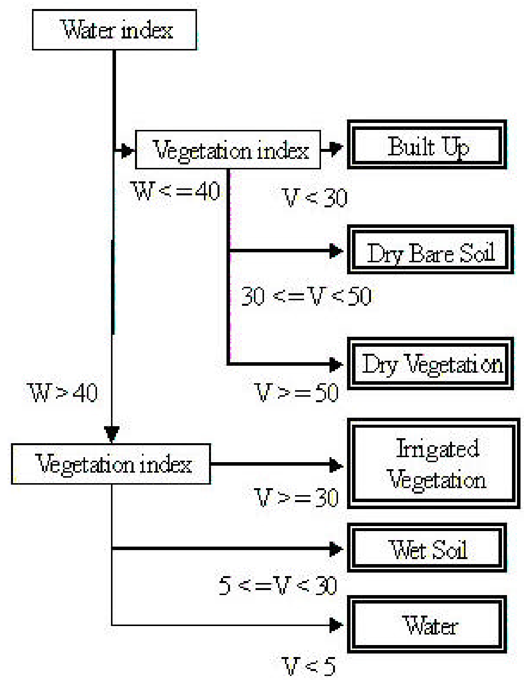

Figure 4 Flow chart to determine the land-cover category of each pixel

Secondly, based on the knowledge of the area and existing land use maps, samples of those land-cover categories were selected and statistics of VSW indices were investigated. Table 1 shows means and standard deviations of VSW indices for 6 main land-cover categories. Base of statistics VSW indices (Table 1) and existing land-use maps, a decision tree to classify land-cover for each change pixel from VSW indices was created (Figure 4). Land-cover categories were, thus, determined for each pixel in both 1993 and 2002 images. Finally, new urban areas were detected and land conversion types were estimated. A sample of new urban expansions in the South of Bangkok is shown in Figure 5.

1993 2002 New urban expansions

Figure 5 Sample of extraction of new urban expansions (1993 - 2002)

3 RESULTS and DISCUSSIONS

Figure 6 shows the expansion of urban areas from 1993 to 2002 in Bangkok Metropolitan Region. And land conversion statistics are shown in Table 2. Total new urban area from this study was 38.4 × 10^3 ha and was found to be converted almost equally from dry bare soil (23.6 %), dry dense vegetation (26.8 %), irrigated dense vegetation (23.5 %), and wet soil (25.2%) land-cover categories.

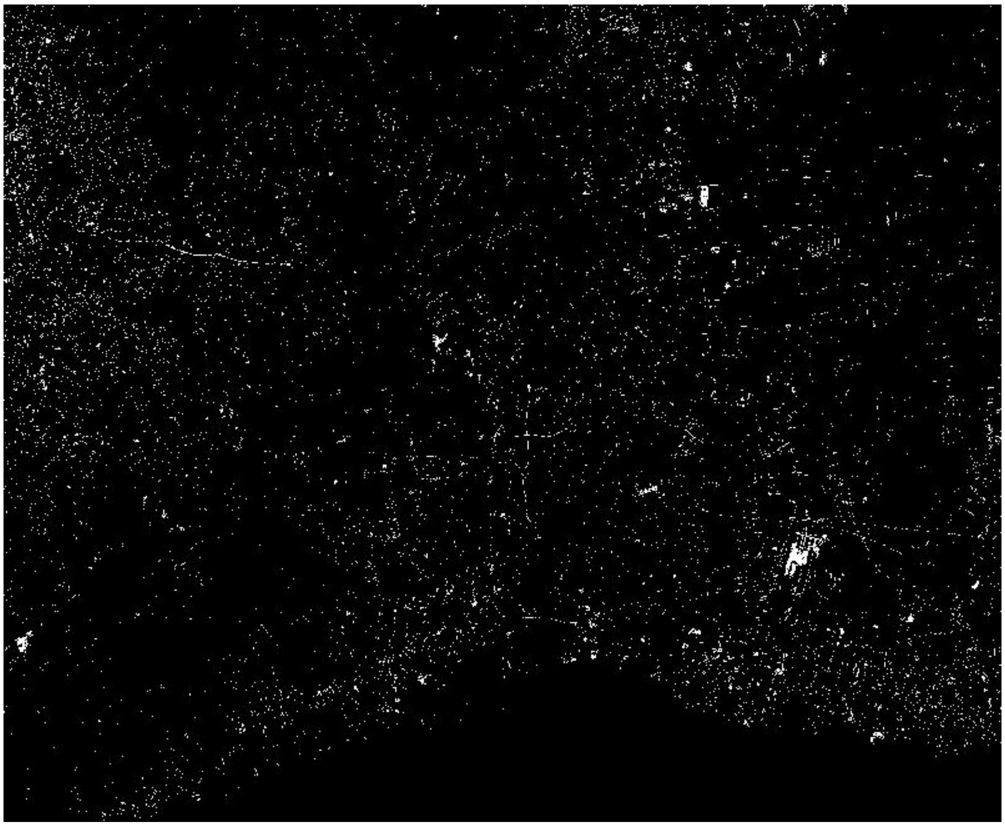

Figure 6. New urban expansions in BMR (1993 - 2002)

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Table 2 Land conversion type to new urban areas.

Land-cover in 1993	Area (× 10^3 ha)	% of total new urban areas
Dry Bare Soil	9.07	23.6
Dry Dense Vegetation	10.3	26.8
Irrigated Dense Vegetation	9.02	23.5
Wet Soil	9.66	25.2
Water	0.369	0.961
Total new urban areas	38.4	100

In this study, we have experimented monitoring of urban expansion in Bangkok Metropolitan Region using linear mixture model. The results seem to have reasonable accuracy. Field works and other change detective methods will be carried out in near future to check the accuracy of this method before applying to other images with different sensor characteristics for long-term urban expansion monitoring.

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