Monitoring of Illegal Dumping Using Satellite Images

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KEY WORDS: Industrial wastes, Illegal dumping, Monitoring system, Remote sensing

ABSTRACT

Illegal dumping of industrial wastes is recently becoming one of the serious social and environmental problems in Japan. Illegal dumping is currently monitored with airplane patrol or ground inspection by local government. However, it becomes more difficult to discover illegal dumping sites with conventional methods since dumping itself is getting crafty. Satellite remote sensing can provide an efficient tool to monitor dumping sites from space since it can observe land surface conditions in quite extensive area regularly and quickly.

Hence, the aim of this study is to develop a financially feasible and practical method for monitoring illegal dumping using remote sensing. In order to do this, this study investigates the method for detecting forest changes caused by dumping by using time series satellite data, especially acquired by medium-resolution sensors (Landsat-TM, ASTER). In addition, this study also evaluated the possibility of its application.

Introduction

Illegal dumping of industrial wastes is recently becoming one of the serious social and environmental problems in Japan. According to the survey of Ministry of the Environment of Japan, the number of illegal dumping cases in Japan has increased annually since 1993. Nonetheless, the amount of illegally dumped wastes has remained on the same level as the past years, at approximately 400,000 tons. (See fig 1 bellow) This means that the scale of illegal dumping has been smaller, and thereby, it becomes more difficult to discover illegal dumping sites.

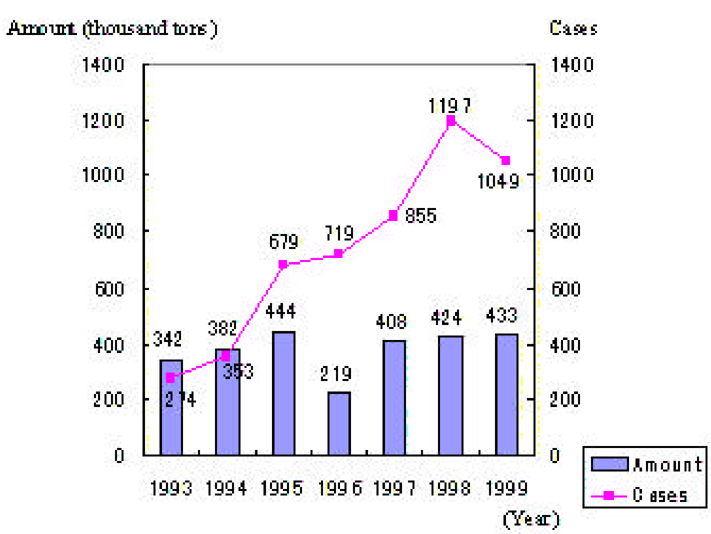


Fig 1. Illegal dumping in Japan (source: Ministry of the Environment of Japan, 2001)

Illegal dumping is currently monitored with airplane patrol or ground inspection by local government.

Both methods, however, have some problems. Airplane patrol cannot be done frequently due to its large cost, and thereby early detention of illegal dumping is impossible. Moreover, the problem of ground inspection is that it is hard to discover in areas where inspection is difficult, such as in the forest. Satellite remote sensing can overcome such problems and can provide an efficient tool to monitor dumping sites from space since it can observe land surface conditions in quite extensive area regularly and quickly. Hence, this study aims at developing a financially feasible and practical method for monitoring illegal dumping using remote sensing.

Applications of remote sensing for monitoring of illegal dumping

In previous works, various methods or sensors have been tested for monitoring the illegal dumping, and the possibility of their application has been examined. Table 1 summarizes the results from these works.

Table 1. Sensors and possibility of their application (source: Ministry of the Environment of Japan, 2001)

Sensors	Algorithms	Possibility of their application
Multi-Spectral Sensors/ Medium Resolution(15-30m)	Detection of forest changes caused by dumping	
Multi-Spectral Sensors/ High Resolution(4m)	Detection of forest changes caused by dumping	High
Panchromatic Sensors/ High Resolution(1m)	Detection of spatial feature change of ground surface	Medium
Thermal Infrared Sensors (Resolution 60-120m)	Detection of thermal emission	Low
Synthetic Aperture Radar (Resolution 30m)	Detection of metal wastes	Medium
Panchromatic Stereo Sensors /High Resolution(2.5m)	Detection of elevation change	Low

This study takes experiences from the above methods using optical sensors. The methods using optical sensors, which involves detection of forests, appears to be useful because forests account for about 60% of all illegal- dumping areas in Japan.

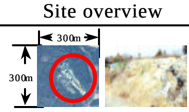
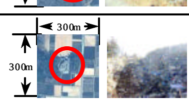
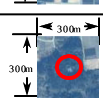
Previous works have attempted to detect forest changes caused by dumping using high-resolution satellite images or medium -resolution satellite images, and showed that it is possible to detect forest changes with high accuracy using high-resolution satellite images, whereas detection using medium-resolution satellite images has many errors. However, from the point of view of cost, it is impossible to monitor illegal dumping only by using high-resolution images. Therefore, it is important to use medium-resolution images to screen out the possible candidates before detailed detection by high-resolution images.

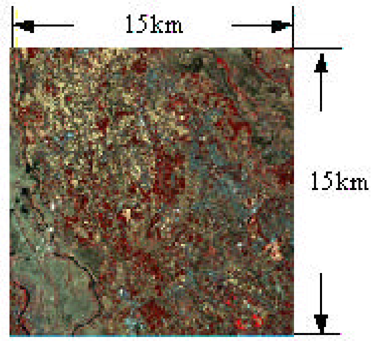
Hence, this study focuses on detection using medium-resolution images, and attempts to improve the accuracy of detection and to evaluate it.

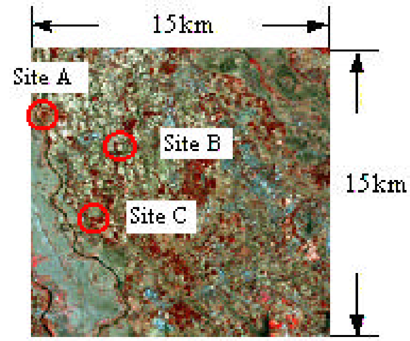
Study area and data set

The study area is located at about 60km north of Tokyo. This area is situated in between latitude 36°01´-36°09´N and longitude 140°00´-140°09´E in Ibaraki Prefecture of Japan. It includes 3 illegal -dumping sites. Table 2 shows the detail of the dumping sites.

Table 2. Detail of dumping sites

	Site overview	Site data	Types of wastes
Site A		Time of dumping: Jun. 1999 Area of dumping: 6,000m^2 Amount of dumping: 75,000m^3	Plastic, timber, rubble, metal
Site B		Time of dumping: Oct. 1997 Area of dumping: 1,900m^2 Amount of dumping: 20,000m^3	Plastic, timber, rubble
Site C		Time of dumping: Nov. 1998 Area of dumping: 850m^2 Amount of dumping: 5,000m^3	Plastic, timber, rubble





Before dumping:
Landsat5 TM (25 Feb 1997 Path: 107, Row:35)

After dumping:
Terra ASTER (15 Feb 2002 Path:107, Row:100)

Fig 2. Overview of Study Area

Fig 2 shows the data used in this study. The two images in fig 2 have different resolutions, and thereby, the resolution of Landsat image (lower resolution) was matched with that of ASTER image (higher resolution) by dividing each pixel into four. Thus, both image have 15m resolution.

Methods for detection of forest changes

This study applies two kinds of methods for detection of forest changes. One uses NDVI value, and the other uses linear mixture model. The detail of each method is as follows:

NDVI method

This method has been applied in previous works, which detect forest changes by capturing decrease of NDVI value. Thus, the Changing Index (CI) is defined as follows:

$$CI = (NDVI)_{pre} - (NDVI)_{post} \quad (1)$$

where $(NDVI)_{pre}$ is NDVI value before dumping, and $(NDVI)_{post}$ is NDVI value after dumping.

VSW method

In general, each pixel of remote sensed images that consists of complicated land cover has mixed information from some categories. Such pixels are called 'Mixel' generally. When 2-channel images (red and near infrared) are used, this method limits these categories to three elements: Vegetation (V), Soil (S), and Water (W), and then, divides each pixel into area ratio of three elements (Sone, 2001). In order to acquire the area ratio, linear mixture model is applied. In this model, spectral pattern of Mixel is expressed as linear sum of the spectral pattern of each category.

$$L = L_v \times A_v + L_s \times A_s + L_w \times A_w + C \quad (2)$$

where L is the spectral pattern of Mixel, $L_v, L_{s,}, L_w$ are the spectral patterns of pure pixel of vegetation, soil, and water, $A_v, A_{s,}, A_w$ are the area ratios of vegetation, soil, and water respectively, and C is error term.

The area ratio of each Mixel is estimated by minimizing error term by using least-squares method.

From the area ratios of V, S, and W, it was found that the ratio of V decreases and that of S increases in the areas where forests decreased. Thus, by using this finding, the Changing Index (CI) can be defined as follows:

$$CI = (A_v)_{pre} - (A_v)_{post} + (A_s)_{post} - (A_s)_{pre} \quad (3)$$

where $(A_v)_{pre}$ and $(A_s)_{pre}$ are the area ratios of vegetation and soil before dumping, and $(A_v)_{post}$ and $(A_s)_{post}$ are those after dumping.

Results and discussions

The results of detection of forest changes using NDVI method and VSW method and their qualitative assessment are described in Section (5.1). The new method combining the both methods described above and the result of detection using it are shown in Section (5.2). The quantitative assessment of the method is explained in Section (5.3).

5.1. Results of detection of forest changes using NDVI method and VSW method

Forest changes were detected using the CI defined in Section 4 by the both methods. Detection algorithm is as follows:

First, the CI is calculated for every pixel and the histogram of the CI value is created, and then 5% of its higher rank is considered as change candidate, and finally, binarized image is acquired by threshold operation. The r esults from this method are shown in fig 3.

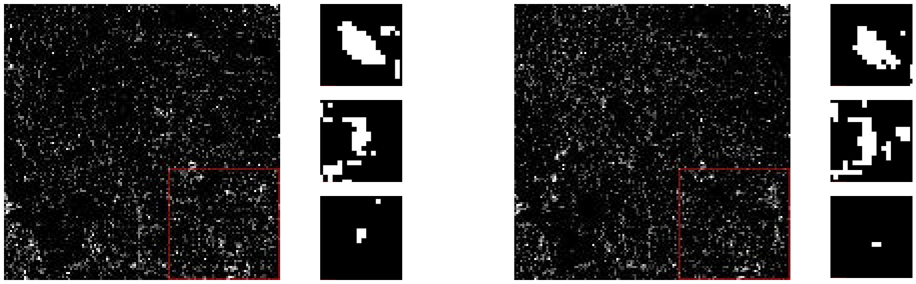


Fig 3. Change-detection images (Left: NDVI method, Right: VSW method)

In fig 3, white areas are allocated to change candidates. Fig 3 shows that both methods detect all of dumping sites. Although it cannot be evaluated which method is superior from this result, each method has different tendency toward change detection and detection errors, which are listed in fig 4.

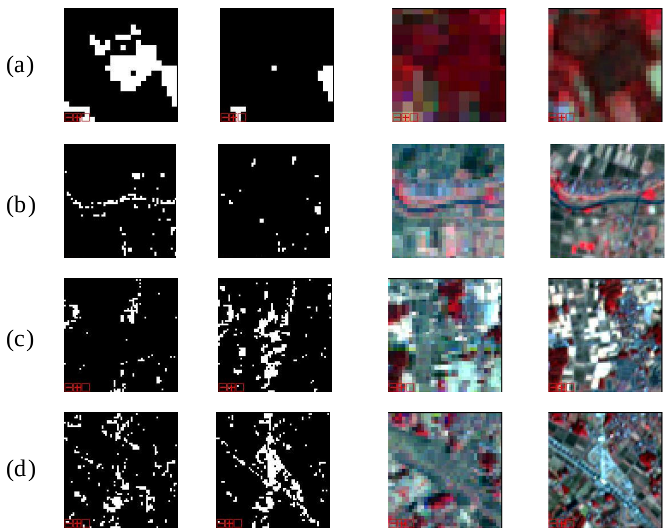


Fig 4. (a) Detection error of NDVI method due to shadow, (b) Detection error of NDVI method due to edge, (c) Detection value of VSW method due to vegetation change in fields, (d) Land-cover change in fields (From the left side, NDVI method, VSW method, Landsat image, ASTER image)

NDVI method mis-detects darker areas due to shadowing (fig 4 (a)) and edges of rivers (fig 4 (b)). On the other hand, VSW method is sensitive to slight changes of vegetation in fields, and thereby, has much mis-detection there (fig 4 (c)). This method, however, has possibility of the change detection in fields that is impossible by using NDVI method (fig 4 (d)).

5.2. New method for detection of forest changes

From the result in Section (5.1), combining NDVI method and VSW method appears to be effective for change detection. Moreover, because the detection area is mixed in forest area, fields, urban area and so on, forest area should be extracted as the target for detection to reduce detection errors. In order to extract forest area, supervised classification using the maximum likelihood classifier was applied in this study.

The method suggested above and its result are shown in fig 5.

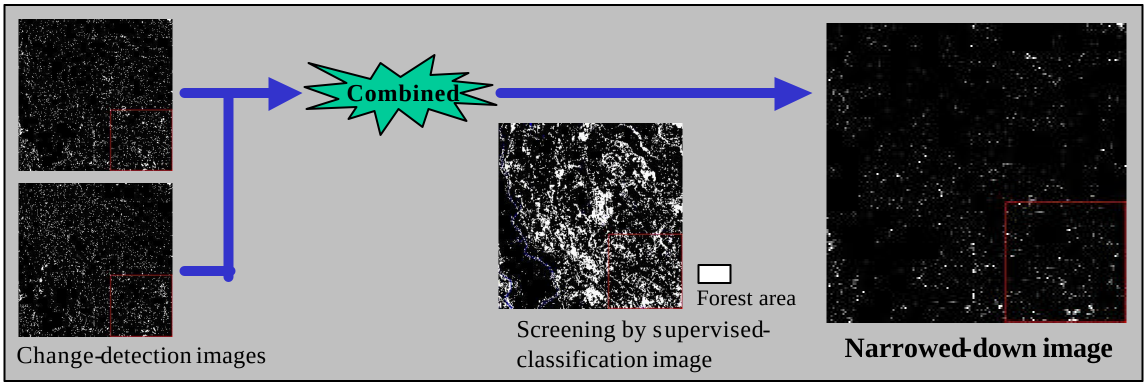


Fig 5. The method for change detection and its result

5.3. Assessment of new method for detection of forest changes

The new method can screen change candidates. The result, however, includes many detection errors. Thus, this study aims at the quantitative assessment on the change-detection accuracy with the change of the size of area under investigation. The assessment algorithm is as follows:

First, the size of each change candidate is acquired, secondly, the histogram of the size is created, and finally, the candidates whose size is small (under 12 pixels) are cut because they are considered to contain many detection errors (See fig 6 bellow). In addition, fig 7 shows the result of cutting small candidates.

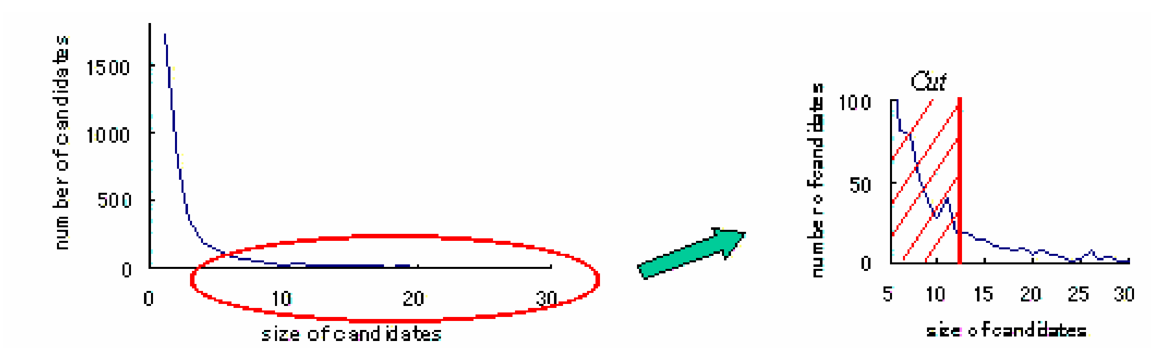


Fig 6. Histogram of the size of change candidates

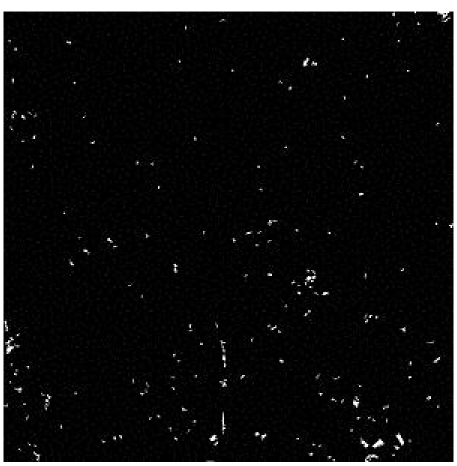


Fig 7. Result of cutting small candidates

Change candidates that exist in fig 7 can be classified into 3 categories.

First category (Category A) includes the areas that actually changed. Second category (Category B) includes the ones that are mis-recognized as forest changes because vegetation change occurred in fields (data-dependent detection error). Final category (Category C) includes the ones that are mis-detected due to the accuracy of geometric correction or the difference of resolution (method-dependent detection error). Fig 8 presents the typical example of each category.

Category A

Category B

Category C

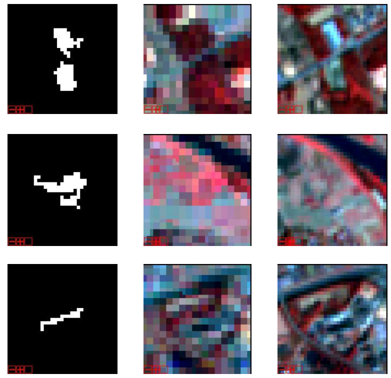


Fig 8. Typical example of each category (From the left side, change candidates, Landsat image, ASTER image)

Change candidates were classified into 3 categories and counted according to size by visual observation. The result is shown in table 3.

Table 3. Candidates included in each category

Category / Size (pixels)	A (Significant change)	B (data-dependent error)	C (Method-dependent error)
12-24	36 (30%)	48 (41%)	33 (29%)
24-	27 (51%)	25 (47%)	1 (2%)

From table 3, it is found that data-dependent errors exist independently of size, whereas method-dependent errors account for 30% of all candidates in case of 12 to 24 pixels (2700 to 5400m^2) and few errors exist in case of over 24 pixels.

Conclusions and future works

This study developed a method for monitoring illegal dumping by detection of forest changes caused by dumping using medium-resolution satellite images, and examined the possibility of its application. The summary is as follows:

Two methods are applied for change detection: NDVI method and VSW method. Although it cannot be evaluated which method is superior, they have different tendencies toward change detection, and thereby, it appears to be effective to combine both methods.

Hence, a new method for detection of forest changes is suggested. It combines NDVI method and VSW method, and moreover, screens change candidates by extracting forest area as the target for detection using supervised classification.

Finally, this study evaluates the proposed method. As a result, it appears to be impossible to apply this method to small dumping sites under about 2000m^2. Although the method can be applied to the sites over about 2000m^2, a number of method-dependent detection errors exist in case of under about 5000m^2, whereas few method-dependent errors exist in case of over about 5000m^2.

However, illegal dumping sites over 2000m^2 account for only about 5% of all dumping sites in Japan now, and thereby, further improvement is needed for application of this method. In order to do this, it is planned to detect changes by using data set acquired by single sensor (especially ASTER) and by improving the accuracy of geometric correction. Moreover, it is also planned to use external data such as GIS data. In addition, if changes can be detected, it cannot be determined whether it is caused by illegal dumping, and thereby, this problem also waits future works.

Acknowledgement

We are most grateful to National Institute of Environmental Studies for providing us with various data and giving us advice to this study.

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