CHANGE DETECTION OF RICE FIELDS AFTER THE GREAT EAST JAPAN TSUNAMI USING TIME-SERIES MODIS DATA

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ABSTRACT

The 2011 Great East Japan Tsunami destroyed rice agriculture in east coastal area of Japan, especially in Fukushima Prefecture and Miyagi Prefecture. The tsunami damaged approximately 23,600 hectares of cultivation area in the region. Monitoring the effect of rice area after the Tsunami is critical to provide agronomic planners with valuable information to devise effective crop management strategies. This study aims to investigate the change detectionof paddy rice after the disaster using Moderate Resolution Imaging Spectroradiometer (MODIS) data from 2010 to 2011. The procedure of data processing consists of four steps: (1) data pre-processing to produce the time-series Normalized Difference Vegetation Index (NDVI) MODIS data; (2) data filtering of the time-series NDVI data using wavelet transform; (3) paddy rice mapping using support vector machine (SVM) and accuracy assessment, and (4) examination of paddy rice. Primary mapping results compared with ground reference data indicated close agreement between the two datasets. The paddy rice areas affected by the 2011 Tsunami were spatially distributed along the coastline. However, results revealed a significant change of paddy rice cultivation between 2010 and 2011. We expect this study can provide useful information for agronomic management in tsunami-affected area in Japan.

INTRODUCTION

On 11 March 2011, the Great East Japan Tsunami occurred in northeast Japan. The powerful earthquake caused tremendous tsunami so that buildings, cars and ships were swept away by a wall of water. Tsunami wave struck the coastal areas and deluged agricultural lands. The earthquake and tsunami also caused the explosion of nuclear plant in Fukushima and destroyed lots of agricultural lands, especially in Miyagi and Fukushima prefectures. Lots of people who living near the nuclear plant have to evacuate.

After the tsunami and the explosion event, local farmers have to face many difficulties, such as salinization, radioactive contamination and facility loss. On the basis of statistics of the Ministry of Agriculture, Forestry and Fishery(MAFF), approximately 23,600 hectares of arable land were damaged by the tsunami, including slightly more than 20,000 hectares of rice paddy. According to the research of Graduate School of Agricultural and Life Sciences, the University of Tokyo(GSALS), the emission of radioactive nuclides from the power plant, which contaminated not only in Fukushima but also nearby areas(T.M. Nakanishi, 2013). ^{137}Cs, and ^{134}Cs, the main radioactive nuclides, were detected in the fallout over the land surface and the fallout absorbed firmly to the leaf surface. Besides, it was estimated that radioactivity might be absorbed by roots(K. Nemoto and J. Abe, 2013). In Sendai, a majority of the agricultural land destroyed by the tsunami and lots of facilities loss, including mainly storage reservoirs, drains, pumps, shore protection facilities for agricultural lands. In Fukushima, most of agricultural lands were restricted to plant any crops(e.g. farmlands in Okuma)due to radioactive contamination and local government took measures immediately to reconstruct and remove radioactivity(T.M. Nakanishi, 2013).Therefore, investigating the change of rice area between 2010 and 2011 is possible to indicate the implication of salinization and radioactive contamination near the nuclear plant.

The time-series MODIS data is generally used to monitor rice fields due to several advantages, including a wide region of coverage, high temporal repeatability, and free for data acquisition. Besides, the time-series data is useful for detecting the change of land use condition over rice fields, based on the phenological information. This study aims to map the locations of rice fields which were destroyed after this disaster. However, there are lots of rice fields around coastal area were destroyed by the tsunami, we selected study area including inland to obtain enough and stable phenological information for classification. After image classification, the results of change detection revealed a significant change of paddy rice cultivation between 2010 and 2011. Rice monitoring and investigating the change of rice fields are an important activity after the Great East Japan Tsunami.

SYUDY AREA

The study area is located in the northeastern region of Japan(Figure 1). Single rice is one of major crop in northeast Japan. Rice is mainly cultivated in plains and is dependent on irrigation availability. Paddy rice is planted from around the end of April to late June and harvested from August to October. Length of a growing cycle is about 140-160 days. We selected study area including inland area and it consists of parts of Yamagata, Miyagi and Fukushima prefectures. The area is around 10,075.09km^2. The inland area was selected because rice fields weren't destroyed by the tsunami due to mountains and provided stable phenological information between 2010 and 2011 for classification based on MODIS NDVI time-series data filtered using wavelet transform.

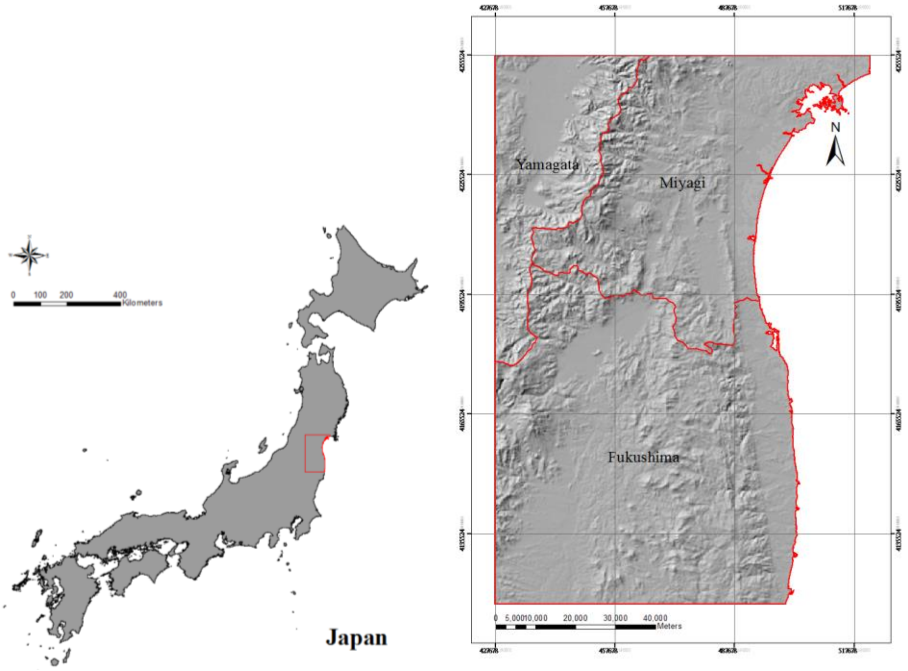

Figure 1. Study area.

MATERIALS

Data collection

The MODIS 250 m data(MOD09Q1 product) obtained from the USGS Land Processes Distributed Active Archive Center (LP DAAC) were used in this study. This data product has two spectral bands: red band(620nm-670nm) and near infrared band(841nm-876nm) at 250-meter resolution in an 8-day gridded level-3 product in the Sinusoidal projection. The product had been already corrected for the effects of gaseous and aerosol scattering(LP DAAC).

The land-use map of the study area in 2009 (scale 1/25000) was provided by the Ministry of Land, Infrastructure, Transport and Tourism(MLIT) in Japan and was used for classification accuracy assessments. This map were originally constructed from ALOS imagery and topographical map (scale 1/25000) and updated to 2010 by digitizing FORMOSAT-II image at the rice heading date(2010/7/27). The map was finally converted to a raster form of 250m resolution and used as ground reference data for accuracy assessments.

We also collected the Tsunami-affected area map from the UNOSAT. It illustrates satellite-detected standing bodies of water remaining after the tsunami event. Flood waters were identified through an analysis of Radarsat-2 satellite data recorded 12 March 2011. This map was converted to 250-m resolution and used as affected area map.

METHODS

Data processing consists of four main steps: (1) Data pre-processing to produce the time-series Normalized Difference Vegetation Index (NDVI) MODIS data, (2) Noise filtering of the time-series NDVI data using wavelet transform, (3) paddy rice mapping using support vector machine (SVM), and (4) accuracy assessment.

Data pre-processing: The study area was extracted from MODIS tile H28V05 and H29V05. The MODIS Reprojection Tools(MRT) developed by LP DAAC can mosaic different tiles together, allow projection to the Universal Transverse Mercator Tokyo Zone 54 North and resample with nearest neighbor algorithm. After that, we calculated NDVI for every 8-day MODIS image to produce the time-series MODIS NDVI data. This study used NDVI to monitor temporal changes in rice fields. To create the time-series dataset for the whole year, then NDVI scenes were stacked into year-long NDVI scenes using 46 bands.

Noise filtering: The discrete wavelet transform method has been applied in many fields for extracting useful information from time-series data. The wavelet transform $W(s, \tau)$ of a signal $x(t)$ is defined as

$$W(s,\tau)=\frac{1}{\sqrt{s}}\int x(t)\,\Psi\left(\frac{t-\tau}{s}\right)dt,$$

where $x(t)$ is input signal; Ψ is the mother wavelet function; and s and τ are scaling and translation parameters determining the width and center of the mother wavelet, respectively. In our study, we used Coiflet(order=4) to reconstruct signals.

Image classification: In order to increase the accuracy, the filtered NDVI data was used to mask out the forest, urban and water area. The Digital Elevation Model(DEM) is also as a threshold to mask out the non-rice area where the elevation is higher than 500m(Table 1). We used the ground truth map as a reference to select the training data. The training data in inland region provide stable phenological information. Then, we used SVM to classify the rice area and non-rice area in 2010.

Table 1. Parameters for masking out non-rice area.

	Threshold 1	**Threshold 2**
Water	NDVI < 0.1	Sum > 15
Urban	-0.05 < NDVI < 0.4	Sum > 30
Forest	NDVI > 0.6	Sum > 25
Elevation	> 500 m	

Accuracy assessment: To check the accuracy assessment in 2010, we randomly selected 200 check points from rice area and non-rice area, respectively. Because the rice fields in inland region wasn't affected by the tsunami directly, we assumed that rice was sustainable production in inland area. Based on the stable phenological information and the accuracy assessment in 2010, we used the training data in 2010 and re-selected the training data in coastal area where was destroyed by the tsunami to classify the data in 2011.

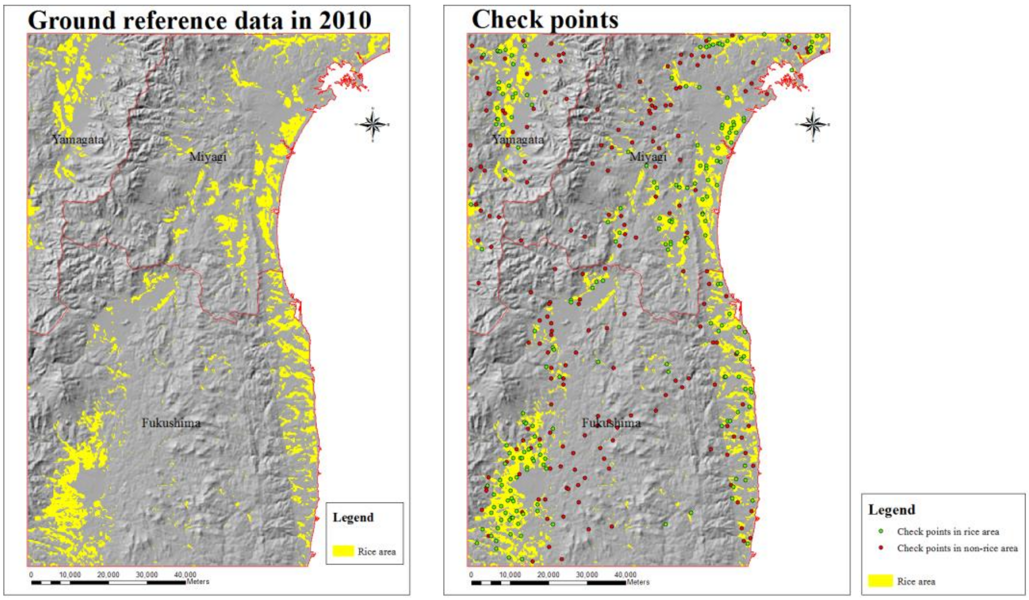

Figure2. Ground reference data in 2010(left) and random points(right).

RESULTS AND DISCUSSION

Due to the resolution of MODIS data, mixed pixel problem lowered the level of classification accuracy. However, the classification approach using the filtered data derived from wavelet transform still can map the rice and non-rice area in Japan. Coiflet(order=4) mother wavelet is suitable for filtering of time-series MODIS data and the temporal profiles may smoothly characterize the temporal changes in rice patterns.

The classification results(Figure 3) showed that the rice fields were spatially distributed along the coastline area. However, there are lots of rice fields located in northeastern coast were destroyed by the tsunami. The classification results in 2010 were assessed using ground reference data(Figure 2) with 400 random points. The overall accuracy, producer's accuracy and user's accuracy is 85%, 86% and 85% , respectively. The kappa is 0.70.

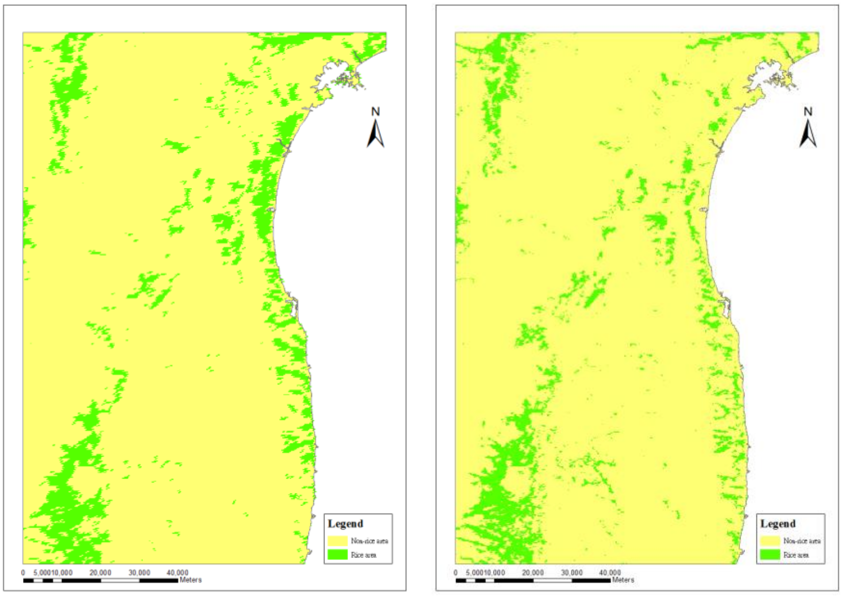

Figure3. Image classification in 2010(left) and 2011(right).

Change in affected area

According to the results(Table 2), there are 65534.4ha rice fields no change in whole study area and planted rice continuously after the tsunami. The ratio indicated that lots of rice fields distributed in inland region and only 1.9%(Type I) located in affected area. Due to the tsunami, there are 43891.7ha rice fields had change and lots of rice fields distributed in coastal area were destroyed. Rice fields losses in the affected area accounted for 16.3% of Type II in study area. Type III, there are 27,205ha rice fields had situation of rice fields increased after the tsunami. Type IV, there are 890,877.9ha rice fields no change but no rice fields.

Table 2. Rice situation in 2010 and 2011.

Type	2010	2011	In study area		In affected area		Ratio
			Area(ha)	%	Area(ha)	%	%
I	Rice	Rice	65,534.4	6.5	1,231.25	11.3	1.9
II	Rice	No rice	43,891.7	4.4	7,162.50	65.6	16.3
III	No rice	Rice	27,205.0	2.7	225	2.1	0.8
IV	No rice	No rice	890,877.9	86.4	2,293.75	21.0	0.3
Total			1,007,509		10,912.5	100	

We were most concerned about rice area changed between the 2010 and 2011(Figure 4). Type I means that rice still survived and kept growing in the affected area after the tsunami. There are 1,231.25 ha rice fields centrally distributed in Wakabaka, Sendai city and located within 3-5 km from coastline. Type II indicated that rice fields were destroyed by the tsunami and didn't grow in the affected area in 2011. There are 7,162.5ha rice fields spatially distributed along the coastline from Miyagi to Fukushima. Type III means that there were no rice growing during the 2010, but rice grew after the tsunami. There are 225ha area belong to type 3 and only 2% in the whole affected area. This type of rice fields scattered around the rice fields of type I. Type IV, there are 229,375ha area destroyed by the tsunami but no rice fields. The situation of type II is an important phenomenon what we are concerned. In coastal area, there are lots of paddy rice fields are threatened by the destructive tsunami.

Rice situation

The change detection indicated rice situation in northeast region of Japan(Figure 4). The coastline showed the affected area within a 5km zone and lots of rice fields losses centrally distributed in this zone, especially in Miyagi. In

Fukushima, rice fields losses in affected area located within a 3km zone. However, there are lots of rice fields losses but not located in affected area. It means the rice fields losses within 10 km to 40km distance from nuclear plant were not destroyed by the tsunami but by radioactivity.

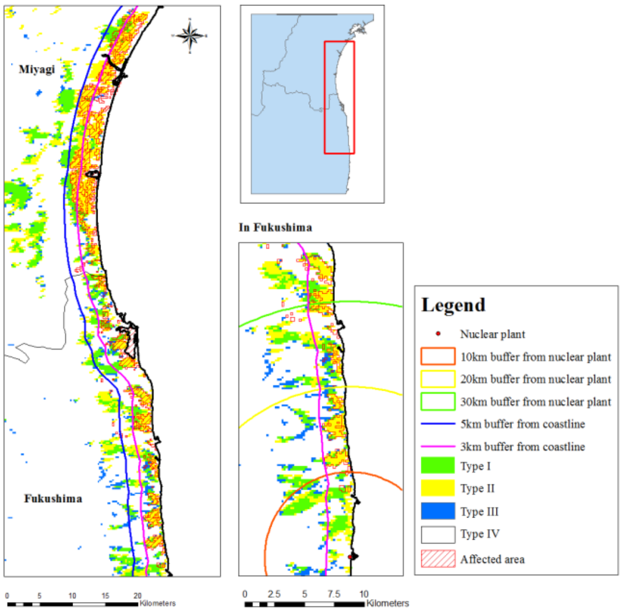

Figure 4. Rice situation in 2010 and 2011.

CONCLUSIONS

In this study, the time-series MODIS data were used for mapping rice fields destroyed after the tsunami in northeast region of Japan. The classification results were affected by the resolution of MODIS sensors, but the results indicated that NDVI profiles derived from wavelet transform reflected the characteristics of rice and can classify different land cover and temporal characteristics of rice were important for classifying image. The overall accuracy, producer's accuracy and user's accuracy is 85%, 86% and 85% , respectively. The kappa is 0.70.

Rice monitoring and investigating the rice fields distribution are an important activity after the Great East Japan Tsunami. There are 7,162.5ha rice fields were destroyed by the tsunami and didn't grow and harvest in the affected area in 2011 and spatially distributed along the coastline from Miyagi(within 5km zone) to Fukushima(within 3km zone). Besides, the rice fields losses in Fukushima within 10 km to 40km distance from nuclear plant were not destroyed by the tsunami but by radioactivity. The implications of radioactive contamination will keep for a long time. Lots of difficulties caused long-term impacts on the affected area and took many years to recover their homes and farmlands.

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