A PRELIMINARY STUDY ON USING NDVI AND NDWI TIME SERIES FOR MONITORING ABANDONED FARMLANDS IN MOUNTAIN AREAS

Asahi Sakuma[1] and Hiroto Shimazaki[2]
[1] National Institute of Technology, Kisarazu College, 2-11-1, Kiyomidai-higashi, Kisarazu-shi, Chiba-ken 292-0041, Japan,
Email: asahi.s119@gmail.com
[2] National Institute of Technology, Kisarazu College, 2-11-1, Kiyomidai-higashi, Kisarazu-shi, Chiba-ken 292-0041, Japan,
Email: shimazaki@c.kisarazu.ac.jp

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ABSTRACT: This study preliminary evaluated the feasibility of Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) time series for mapping abandoned farmlands in mountainous areas in Chiba prefecture, Japan. NDVI and NDWI time series was derived from 8-day composite of MODIS Surface-Reflectance Products (MOD09Q1 and MOD09A1) for the period from 2002 to 2013. Noise components in both time series data, which were induced mainly by cloud contamination and atmospheric variability, were reduced with the method based on Savitzky-Golay filter. The refined time series data were then decomposed into trend, seasonal, and reminder components. A simple linear regression model was fitted to the trend component for each pixel, and model parameters (i.e., intercept and slope) were estimated to be used as the features useful to detect abandoned farmlands in the pixel area. This idea was based on the assumption that the cessation of cropping activity and flood control in paddy would be reflected in the trend component of NDVI and NDWI time series, and its intercept and slope would have different pattern between farmlands and abandoned farmlands. Discrimination performance of the features was evaluated with the area under the receiver operating characteristic (ROC) curve (AUC). The results showed that all candidate features were poor (AUC < 0.6) in terms of classification performance, being contrary to our intention. Considering the poor performance could be mainly caused by low spatial resolution of MOD09 products, we concluded that the use of remotely-sensed data with higher spatial resolution would be required for mapping abandoned farmlands in mountainous areas.

1. INTRODUCTION

Abandoned farmland, which can be restated as the deserted arable land resulting from cessation of agricultural activities, is gradually increasing in mountainous areas in Japan. Increase of abandoned farmland is considered as a problem that will cause many difficulties such as: expansion of breeding habitat potentially preferred by vermin; increase of small parcels where illegal dumping frequently occurs; and deterioration of rural landscapes. To address this problem, it is important to periodically identify the extent and distribution of abundant farmland over a broad spatial range.

Area data of abandoned farmland is available from the agricultural census which has been implemented every 5 years (Ministry of Agriculture, Forestry and Fisheries, Japan, 2014). However, since the census data is summarized on the basis of old municipality units, its spatial resolution is too coarse to identify the location of abandoned farmlands. Although a nationwide field survey aiming to cover every parcels of abandoned farmland has also been conducted (Ministry of Agriculture, Forestry and Fisheries, Japan, 2008), its outcome data has not yet been opened to the public. Moreover, such survey efforts could be constrained in future by the limitations of fund, time and human resources. It is hence expected to use cost-effective method for mapping abandoned farmlands.

Remote sensing provides us with a low cost, repeatable alternative means for mapping abandoned farmland over a broad spatial range (Kato et al., 2003; Mino et al., 2005; Zukemura et al., 2011). A previous study suggested that Normalized Difference Vegetation Index (NDVI) derived from remotely-sensed data could have potential to discriminate between a rice paddy and an abandoned rice paddy since the difference in NDVI becomes particularly obvious at the periods of one month after planting and two months after harvesting (Zukemura et al., 2011). Normalized Difference Water Index (NDWI) was also applied successfully to detecting changes in agricultural activity in rice paddy (Mino et al., 2005). However, broad applicability of the previous methods is not necessarily guaranteed since their success relies on acquiring the data not affected by cloud contamination at the suitable timing in terms of crop calendar. Considering the difficulty of avoiding cloud contamination and the variability of crop calendar caused by differences in cultivar and environmental conditions, more robust method is needed.

We preliminary evaluate the feasibility of time series of NDVI and NDWI, which was derived from 8-day composite of MODIS Surface-Reflectance Products (MOD09Q1 and MOD09A1) for the period from 2002 to 2013, for mapping abandoned farmlands. Although the spatial resolution of NDVI and NDWI time series is quite low as compared to the typical size of abandoned farmlands, it is expected that their high temporal resolution contributes to reduce the effects of cloud contamination and crop calendar variability. If the NDVI and NDWI time series is shown to be effective in mapping abandoned farmlands, a nationwide retrospective analysis of agricultural activity will be realized, and this helps us to specify where field survey efforts should be focused.

2. MATERIAL AND METHODS

2.1 Ground Reference Data

The number of parcels of abandoned farmland was counted for each of the 250 m square grids corresponding to the pixel of MOD09Q1 product, based on the visual inspection of aerial photographs taken between 2002 and 2013 over the entire range of study area (Figure 1). The study area was selected as one of the region having a problem relating to abandoned farmlands. Although the study area is covered by various land-use and landcover types with a varied topography, we focused only on the mountainous area where mean slope angle is over 10 degree.

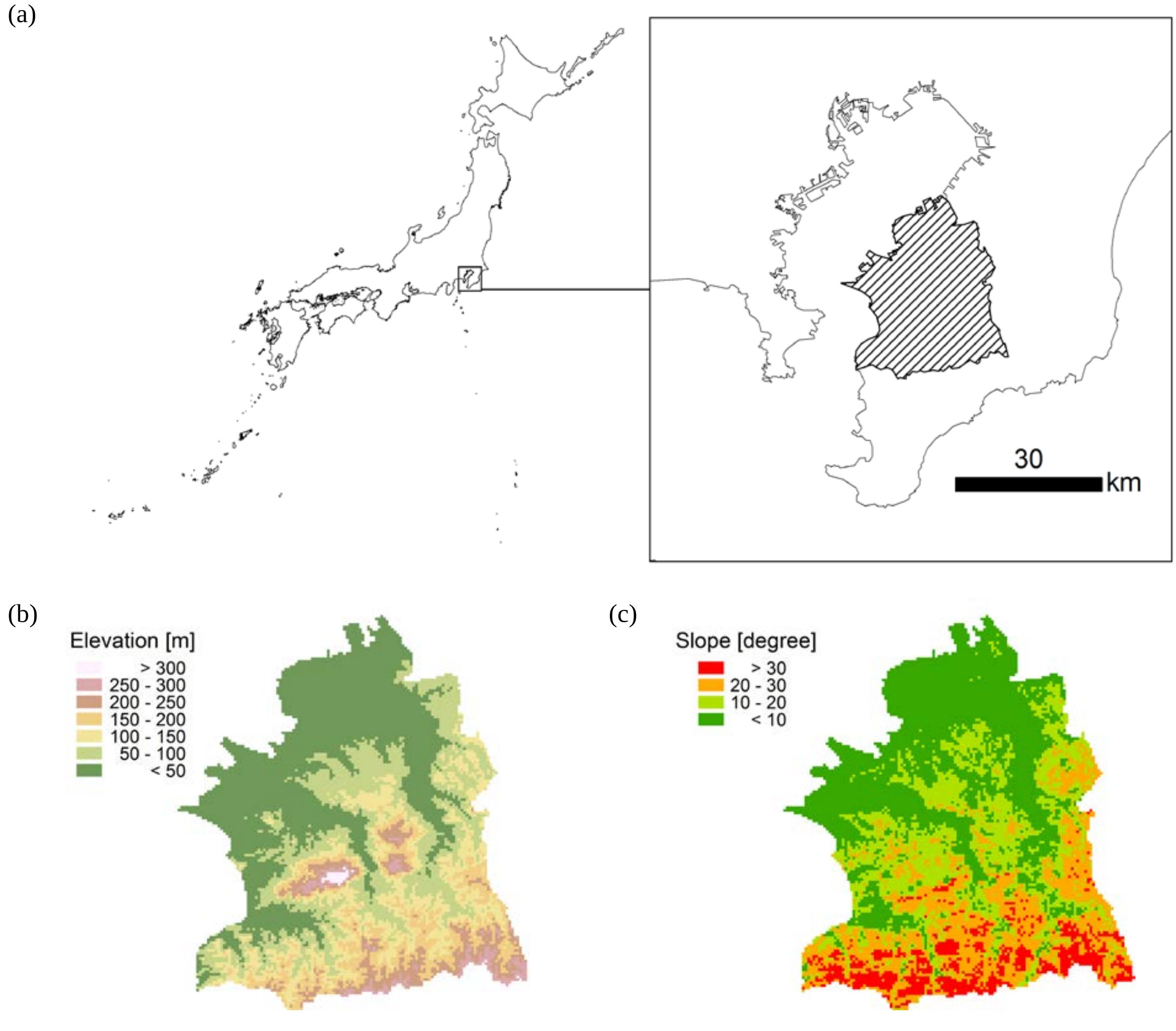


Figure 1. Location (a), elevation (b) and slope (c) of study area.
The hatched polygon in Fig.1(a) represents the spatial extent of study area.

2.2 Generating NDVI and NDWI Time Series

MODIS Surface-Reflectance Products we used were the 8-day composite with 250-meter spatial resolution (MOD09Q1) and the 8-day composite with 500-meter spatial resolution (MOD09A1). They were obtained for the period between 2002 and 2013 from the Reverb Interface of the Earth Observing System Data and Information System (EOSDIS) maintained by National Aeronautics and Space Administration (NASA) (Earth Observing System Data and Information System, 2009). The MOD09Q1 and MOD09A1 products we obtained were first resampled to the universal transverse Mercator (UTM) zone 54 projection with 250-meter spatial resolution, and then subset to a small portion containing the study area.

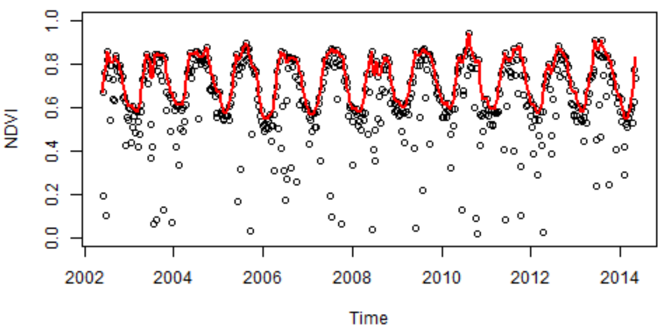
NDVI and NDWI time series were derived from the subset version of MOD09Q1 and MOD09A1 products respectively, using the equations below.

$$NDVI = \frac{\rho_{NIR} - \rho_{\mathrm{Red}}}{\rho_{NIR} + \rho_{\mathrm{Red}}}, \quad (1)$$

$$NDWI = \frac{\rho_{NIR} - \rho_{SWIR}}{\rho_{NIR} + \rho_{SWIR}}, \quad (2)$$

where ρRed, ρNIR and ρSWIR are the surface reflectances for MODIS bands 1 (620-670 nm), 2 (841-876 nm) and 7 (2105-2155 nm), respectively (Gu et al., 2008). Noise components in both NDVI and NDWI time series, which were induced mainly by cloud contamination and atmospheric variability, were then reduced with the method based on Savitzky-Golay filter (Chen et al., 2004) (Figure 2).

(a)



(b)

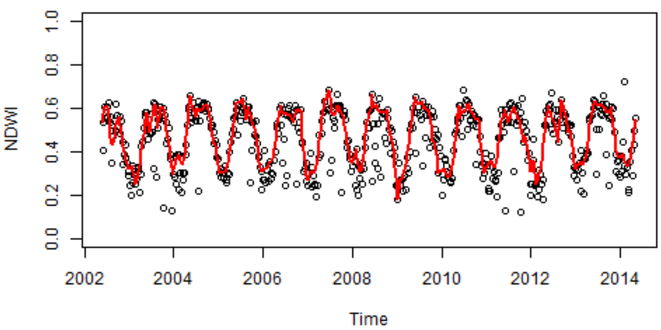


Figure 2. An example of NDVI (a) and NDWI (b) time series.
The open dots indicate the original version while the red lines represent the refined version.

2.3 Feature Extraction from NDVI and NDWI Time Series

Assuming an additive decomposition model, the refined version of NDVI and NDWI time series were decomposed into trend component (T_i), seasonal component (S_i) and random component (e_i) with the decompose function implemented in R (R Development Core Team, 2011):

$$NDXI_i = T_i + S_i + e_i, \tag{3}$$

where $NDXI_i$ is the refined version of NDVI and NDWI time series, and i is the time index (Figure 3).

A simple linear regression model was fitted to the trend component for each pixel (Figure 3), and model parameters (i.e., intercept and slope) were estimated to be used as the features for detecting abandoned farmlands in the pixel area. This idea was based on the assumption that the cessation of cropping activity and flood control in paddy would be reflected in the trend component of NDVI and NDWI time series, and its intercept and slope would have different pattern between farmlands and abandoned farmlands.

(a)

(b)

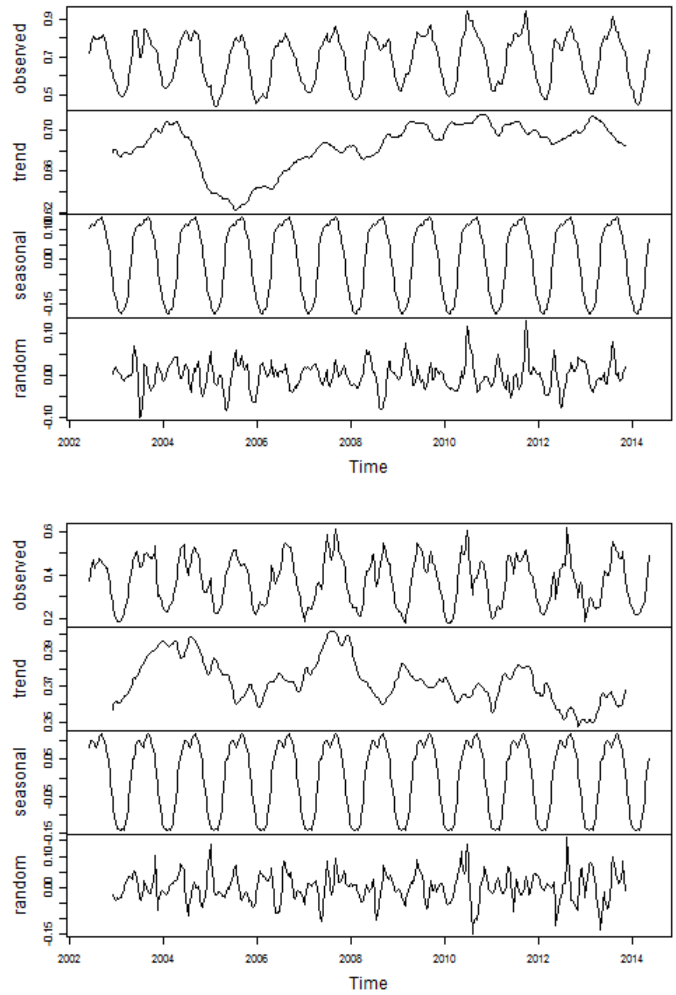


Figure 3. Examples of decomposition of the refined version of NDVI (a) and NDWI (b) time series.

2.4 Assessment of Discrimination Power

Discrimination power of candidate features, which is the capacity to correctly predict the existence of abandoned farmland in a given pixel, was assessed using the area under the curve (AUC) derived from a receiver operating characteristic (ROC) curve (Hosmer & Lemeshow, 2000). The ROC curve depicts the relation between the false positive fraction (FPF; 1−specificity) on the X-axis and the true positive fraction (TPF; sensitivity) on the Y-axis for a range of thresholds. If all predictions were the results of chance only, the relation would be a 45 degree line. Desired feature performance is characterized by a curve that maximizes TPF for low values of FPF. The AUC derived from the ROC curve represents the probability that the extracted feature assigns a higher probability of the existence of abandoned farmland to a randomly selected pixel containing abandoned farmlands than to a randomly selected pixel containing no abandoned farmland. It is equivalent to the Wilcoxon-Mann-Whitney statistic test of ranks (Hanley & McNeil, 1982). AUC values between 0.5–0.7, 0.7–0.8, 0.8–0.9, and >0.9 were considered poor, acceptable, excellent, and outstanding, respectively (Hosmer & Lemeshow, 2000).

3. RESULT AND DISCUSSION

The results showed that all candidate features (*i.e.*, the intercept and slope of the linear regression model fitted to trend component) were poor (AUC < 0.6) in terms of discrimination power (Figures 4 and 5), being contrary to our intention. This poor performance could be caused mainly by the mixture effect of landcover types due to the low spatial resolution of MOD09 products. In addition to this mixture effect, the interannual variation of plant growth controlled by climate conditions (Ishihara et al., 2004) might affect the discrimination power adversely even if the land-use type remains unchanged.

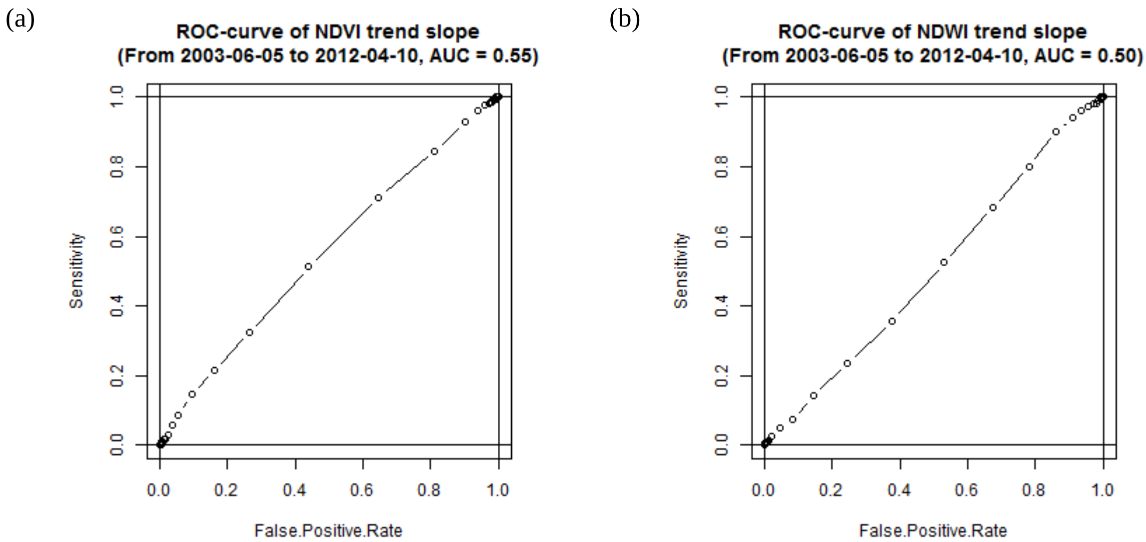


Figure 4. ROC-curves depicted for the trend slopes of NDVI (a) and NDWI (b) time series for the period between 2003 and 2012.

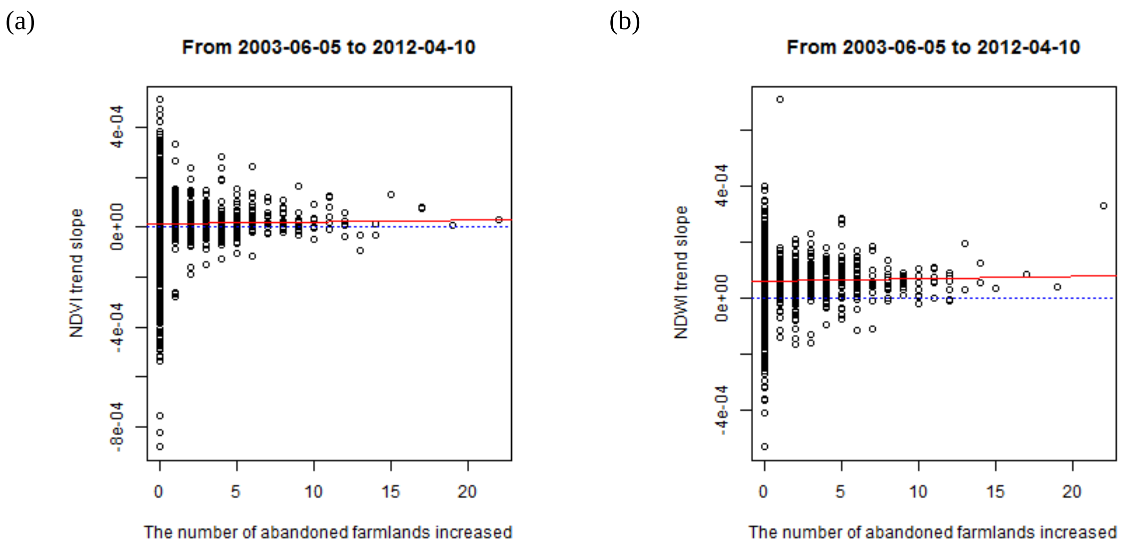


Figure 5. Effects of the number of abandoned farmlands increased during the time frame between 2003 and 2012 on the trend slope of NDVI (a) and NDWI (b) time series.

4. CONCLUSION

We concluded that the use of remotely-sensed data with higher spatial and temporal resolution would be required for mapping abandoned farmlands in mountainous areas, while continuing our efforts to extract more effective features from the NDVI and NDWI time series with low spatial resolution.

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