Identification of paddy fields using temporal NDVI changes in Minamiaso Village, Kumamoto Prefecture, Japan to estimate groundwater recharge

H Amano¹, Y Iwasaki² and T Ichikawa¹

1 Liberal Arts Education Center, Kumamoto Campus, Tokai University, 9-1-1 Toroku, Higashi-ku, Kumamoto 862-8652, Japan
2 Department of Electrical Engineering and Computer Science, Faculty of Industrial and Welfare Engineering, Tokai University, 9-1-1 Toroku, Higashi-ku, Kumamoto 862-8652, Japan
E-mail: ah069881@tsc.u-tokai.ac.jp

Abstract. In Minamiaso Village (Kumamoto Prefecture, Japan), land covers of forests, grasslands, and paddy fields play an important role in groundwater recharge. The land covers have been changed in a past few decades by agricultural systems and natural disasters: landslides, slope failures, and damage of irrigation canals caused by the 2016 Kumamoto earthquake in Japan. In this study, we extracted training data for classifying the land covers, and detected the temporal change of NDVI (Normalized Difference Vegetation Index) for each land cover. To quantify the impact of past land cover change on the groundwater recharge, we need to grasp the area of each land cover with the different hydrological parameters such as infiltration capacities. In the case of paddy fields, its distribution also should be known because the infiltration rates that we investigated vary depending on the paddy fields. We attempted to identify the paddy field distribution by the obtained NDVI values, and confirmed that the paddy field areas near the earthquake faults damaged by the earthquake where are still not usable were well distinguished. The paddy field distribution based on NDVI was almost matched with that based on SAR.

1. Introduction
Aso Caldera in Kumamoto Prefecture, located in the center of Kyushu Island in Japan (figure 1), is the source of six rivers in Kyushu Island, and plays a major role in the water cycle in Kyushu Island. Aso Caldera stores a rich groundwater, and many studies on the groundwater and the water cycle system have been done [1-3]. Minamiaso Village whose area is surrounded with the blue dotted line in figure 1 is one of the three municipalities in Aso Caldera, and is located in the south-west of the caldera. The groundwater recharged at forests and grasslands springs out from multiple large and small spring sources. The quantities of spring water from Shirakawa Spring Source and Takezaki Spring Source reach 60 tons and 120 tons per minute, respectively [2]. Therefore, paddy field agriculture using spring water and pumped groundwater is actively practiced in Minamiaso Village. Flooded paddy field is a one of the important groundwater recharge area in addition to forest and grassland. The forests, grasslands, and paddy fields occupy a large part of the area in Minamiaso Village so that it is recognized that the maintenance of these land covers is essential for preservation of groundwater.

The grassland, which has larger groundwater recharge rate compared to the forest [4], has been maintained by artificial disturbance such as Noyaki (open burning) and mowing. Noyaki (open burning) means burning the grasslands to prevent shrub growth and the transition to forests, and to exterminate
noxious insects [5]. However, a large part of grasslands has been transitioning to forests mainly due to the decrease and ageing of farmers who are managers. On the other hands, the paddy fields significantly decreased because of policy of reducing rice acreage. Moreover, the Kumamoto earthquake (main shock) occurred on April 16, 2016 gave serious damages such as the reduction of grassland and forest areas due to landslide disasters, and the suspension of paddy field agriculture due to the damage of irrigation canals. To quantify the impact of past land cover changes on the groundwater recharge, we need to grasp the area of each land cover with the different hydrological parameters such as infiltration capacities. In the case of paddy fields, its distribution also should be known because the infiltration rates that we investigated vary depending on the paddy fields as shown in figure 1.

To identify and classify the land covers, satellite remote sensing is effective. Classification of land covers and the evaluation for the transition of land covers using NDVI (Normalized Difference Vegetation Index) have been done [6-9]. We have detected the locations of landslide disasters in Aso using NDVI values at two periods before and after the earthquake [10]. Our final goal is to grasp the land covers change in a past few decades including recent natural disaster using BDT (Binary Decision Tree) based on NDVI. In this study, we extract training data, and detect the temporal change of NDVI for each land cover. To measure accurately the temporal change of NDVI for each land cover, we measure in detail the temporal change of NDVI for each crop specie in paddy fields and upland fields, and for each plant in grasslands. Then, we attempt to identify the paddy field distribution by the obtained NDVI values, and confirm the paddy field areas near the earthquake faults damaged by the earthquake. We also compare the paddy field distribution based on NDVI with that based on SAR.

![Map of Aso Caldera and Minamiaso Village](image)

**Figure 1.** The locations of Aso Caldera and Minamiaso Village, and infiltration rates of paddy fields.

2. **Materials and methods**

2.1. **Location of each land cover**

In order to evaluate the temporal change of NDVI for each land cover, it is first necessary to obtain the location of each land cover. As for agricultural crops, we selected the species with a cultivation area of 10 ha or more based on 2016 account book of paddy field for Minamiaso village. We calculated the area of each species for each village division, Oaza, selected the five fields with larger areas so as to exceed 10% of the total area, and identified the positions of selected fields using “Agriculture land information system agriculture committee” [11]. As for damaged paddy fields, because it is unclear how the damaged paddy fields will be used after the earthquake, we analyzed all damaged paddy fields of 900 m² or more to understand the average NDVI characteristic. Forests (conifers and hardwoods), grasslands, lawns,
and bare lands were specified from “1/25,000 vegetation survey (6th and 7th)” [12]. We specified buildings such as elementary and junior high schools, government offices with large site areas, and temporary houses built after the earthquake from Google maps satellite view. Table 1 shows the details of the classification of land covers specified in the analysis.

| Large category | Medium category | Small category | Data source                  |
|----------------|-----------------|----------------|------------------------------|
| Paddy field    | P               | Paddy field    | Account book of paddy field  |
|                | P1              | Akigeshiki rice|                              |
|                | P2              | Koshihikari rice|                             |
|                | P3              | Hitomebore rice|                              |
|                | P4              | Hinohikari rice|                              |
|                | P5              | Morinokumasan rice|                         |
|                | P6              | WCS            |                              |
|                | P7              | WCS - Italian ryegrass|                  |
| Damaged paddy field | DP            | Damaged paddy field | Account book of paddy field |
| Upland field   | U               | Upland field   |                              |
|                | U1              | Italian ryegrass|                              |
|                | U2              | Aoba millet    |                              |
|                | U3              | Aoba millet - Italian ryegrass|    |
|                | U4              | Italian ryegrass - Italian ryegrass| |
|                | U5              | Natsu kansou (Setaria) |                  |
|                | U6              | Buckwheat      |                              |
|                | U7              | Soybean        |                              |
| Conifer        | C               | Conifer        |                              |
| Hardwood       | H               | Hardwood       |                              |
| Grassland      | G               | Grassland      | 1/25,000 vegetation map      |
|                | G1              | Japanese pampas grass|                |
|                | G2              | Turf           |                              |
|                | G3              | Bamboo grass - Japanese pampas grass| |
|                | G4              | Pasture        |                              |
| Building       | B               | Building (House, School, Town office) | Google maps satellite view |
|                | PG              | Plastic Greenhouse | Account book of paddy field |
|                | PG1             | Tomato         |                              |
|                | PG2             | Asparagus      |                              |
| Bare land      | BL              | Bare land      | 1/25,000 vegetation map      |

2.2. Preprocesses and analysis of satellite images

To detect temporal changes of NDVI for areas of classified land covers, we selected the Landsat-8 multispectral images of five periods with extremely few clouds of year 2016 on January 16, March 23, May 23, August 11, and October 20. These images were downloaded from LandsatLook Viewer [13]. In Aso caldera, it is too difficult to obtain Landsat-8 images with no clouds in the higher time resolution because Aso caldera is easily covered by clouds due to the geographical feature. Landsat-8 has Operation Line Imager (OLI) and Thermal Infrared Sensor (TIRS), and acquires 11 bands with different wavelengths. NDVI is calculated by equation (1) from the band 4 (visible red band) and band 5 (near-infrared band).

$$\text{NDVI} = \frac{(\text{NIR} - R)}{(\text{NIR} + R)}$$

where \(\text{NIR}\) is the reflectance of the near-infrared band, and \(R\) is the reflectance of visible red band. NDVI outputs the values between -1.0 and 1.0 which represents the activity level of vegetation. We calculated
the mean values of NDVI in the polygons of determined locations, and evaluated temporal change of NDVI for each land cover. We also attempted to extract paddy fields based on the obtained NDVI values. Moreover, we attempted to extract paddy fields using two SAR (Synthetic Aperture Radar) data at different periods [14]. We used the C-band vv polarization Sentinel-1 SAR images on May 26, and August 30, 2016, which were downloaded from Copernicus Open Access Hub [15]. The rice planting season in Minamiaso Village is May. Therefore, the image on May 26, 2016 shows flooded paddy fields. In flooded paddy fields, the irradiated microwaves are specularly reflected, so that the backscattering is small and they are displayed in black. However, water areas such as rivers in the image are also displayed in black. As an image to mask such areas, we used the image on August 30, 2016 when the rice grew and the backscattering increased. When the difference between the SAR images at the two periods is calculated, it is considered that the gray levels in the paddy fields where the backscattering greatly changes are higher than those of other land covers. So, the regions with high gray levels in the difference image were extracted as paddy fields.

3. Results and discussions

3.1. Temporal changes of NDVI for small category
Figure 2 shows obtained temporal change of NDVI for each land cover. The trends of the temporal changes of NDVI for paddy fields shown in figure 2a are similar each other regardless of the crop species. NDVI values decrease from March to May due to rice planting after puddling in May. On the other hand, we consider that NDVI value increases due to weed breeding because damaged paddy fields (DP) are to be left without puddling. Italian ryegrasses (P7), secondary crops in paddy fields, are seeded in October, and are harvested from mid-April to early May. Thus, we consider that NDVI value from January to March of Italian ryegrasses (P7) is higher than other crop species because Italian ryegrasses grow from winter to spring.

The trends of the temporal changes of NDVI for upland fields shown in figure 2b are almost similar each other except for Italian ryegrasses (U1), buckwheat (U6), and soybeans (U7). This is because the cultivation time differs depending on the crop species. The NDVI values of forage crops are generally higher than those of buckwheat (U6) and soybeans (U7). This may be because forage crops regenerate after harvesting.

The NDVI values of forests (conifers (C) and hardwoods (H)) shown in figure 2c increase from January to August, which correspond to seasonal changes. In the grasslands of Aso Caldera, Noyaki (open burning) is performed in early March. Thus, unlike forests, the NDVI values of grasslands do not increase from January to March. The NDVI values of turf (L) in golf courses show a decrease in August, which are different from the NDVI values of paddy fields, upland fields, forests (conifers and hardwood), and grasslands. The cause is not clear, but is presumed to be related to the type of turf used in the golf courses.

The NDVI values of buildings (B) shown in figure 2d indicate a peak in May. The trend of the temporal change of NDVI of buildings (B) is similar to that of turf in the golf courses. The harvest time of tomatoes is from July to September, that of asparagus is in May, and the two harvest times are different. So, we predicted that the temporal changes of NDVI of tomatoes and asparagus are also different. However, they (PG1 and PG2) show almost the same changes. Because the spatial resolution of the satellite images is 30 m, it may represent the characteristics of the surrounding ridgeways and upland fields rather than the plastic greenhouses. The NDVI values of bare lands are almost no change, and are close to zero.
Figure 2. Temporal changes of NDVI based on small category: (a) paddy field and damaged paddy field; (b) upland field; (c) conifer, hardwood, grassland and lawn; (d) building, plastic greenhouse and bare land.

3.2. Temporal changes of NDVI for medium category

Figure 3 shows the temporal changes of NDVI for the ten medium categories shown in table 1, which are the averages of those for the small categories shown in figure 2. The NDVI values of paddy fields of rice planting time on May are lower than the others. Thus, the areas where NDVI values on May are less than 0.2174 are extracted first. The value 0.2174 is the mean value of P7 (WSC - Italian ryegrass) with the highest NDVI value for paddy fields on May. However, by using this threshold value, the areas of bare lands, plastic greenhouses, and buildings are also extracted. Next, by using the NDVI values on August, these three areas are separated from paddy fields. The threshold value is 0.3414 of P6 (WCS) with the lowest NDVI value (mean value minus standard deviation) for paddy fields on August. However, the area above 600 m a. s. l. on Aso central cone and above 500 m a. s. l. on outer rim were excluded.

Figure 4 shows the analysis results. Figure 4a shows the paddy fields in JAXA (Japan Aerospace Exploration Agency) high-resolution land use and land cover map of Japan [16] which provides the average situation from 2006 to 2011 with a resolution of 10 m before the earthquake. Figure 4b shows the distribution of paddy fields obtained by the method described above. Figure 4c shows the distribution of paddy fields identified based on SAR which is described in Section 2.2. Figure 4d is a superposition of figure 4b,c for comparison. The extracted area of paddy field in figure 4b is 11,325,898 m². This area generally corresponds to the area of 11,999,675 m² reported by account book of paddy field. Comparing figure 4a and 4b, it is obvious that the paddy fields decreased. Especially, the areas near the earthquake faults shown in yellow lines [17] in figure 4, which were confirmed to have appeared on the ground.
surface when the earthquake occurred, are still damaged, and still cannot be used as paddy fields. Figure 4b,c seems to represent the situation well. The distributions of paddy fields in figure 4b,c are almost the same, but the area seems to be smaller in figure 4b. Because the NDVI threshold values and the order of extraction for land covers affect the areas of extracted paddy fields, we will consider these points in a future work.

**Figure 3.** Temporal changes of NDVI based on medium category.

**Figure 4.** Distribution of paddy fields based on different data sources: (a) JAXA; (b) NDVI; (c) SAR; (d) NDVI and SAR.
4. Conclusions
In this study, we extracted training data, and investigated the temporal changes of NDVI. The obtained NDVI values showed the characteristics changed depending on land covers and season. For example, the NDVI values are low in paddy fields in rice planting time and in grasslands in Noyaki (open burning) season. Then, we attempted to identify the paddy field distribution by the obtained NDVI values, and confirmed that the paddy field areas near the earthquake faults damaged by the earthquake where were still not usable were well distinguished. The extracted area of paddy field generally corresponds to the area reported by account book of paddy field. The distribution of paddy fields based on NDVI is generally good agreement with that based on SAR. The purpose of identifying the paddy field distribution is to estimate the groundwater recharge in the area.

We plan to identify the distribution of other land covers, such as grasslands, forests (conifers and hardwoods), and upland fields, using the temporal change of NDVI for this study as training data. Then, we will quantify the impact of past land cover changes on the groundwater recharge.

5. References
[1] Shimotsu M 1986 On the characteristics of groundwater in the hydrologic cycle of the Aso Volcano J. Jpn. Assoc. Groundwater Hydrol. 28 1-13 (in Japanese with English abstract)
[2] Shimano Y 1997 Hydro-chemical study of spring waters in the Aso caldera, central Kyushu Bunsai bulletin 8 43-67 (in Japanese)
[3] Kagabu M, Shimada J, Shimano Y, Higuchi S and Noda S 2011 Groundwater flow system in Aso caldera J. Jpn. Assoc. Hydrolog. Sci. 41 1-17 (in Japanese with English abstract)
[4] Kudo K, Shimada J, Maruyama A and Tanaka N 2016 The quantitative evaluation of groundwater recharge rate using Displacement Flow Model with stable isotope ratio in the soil water of difference vegetation cover Jpn. Groundwater Hydrol. 58(1) 31-45 (in Japanese with English abstract)
[5] Yasunaka Y, Oishi K, Anzai H, Miwa M, Kumagai H, Hirooka H and Ieiri S 2015 Asseing the effects of controlled burning and grazing on vegetation change in the grasslands of Aso region using satellite images analyses J. Jpn. Agric. Syst. Soc. 31 117-125 (in Japanese with English abstract)
[6] Lunetta R S, Knight J F, Ediriwickrema J, Lyon J and Dorsey Worthy L 2006 Land-cover change detection using multi-temporal MODIS NDVI data Remote Sens. Environ. 105 142-154
[7] Jia K, Liang S, Wei X, Yao Y, Su Y, Jiang B and Wang X 2014 Land cover classification of Landsat data with phenological features extracted from time series MODIS NDVI data Remote Sens. 6 11518-11532
[8] Li Y, Cao Z, Long H, Liu Y and Li W 2017 Dynamic analysis of ecological environment combined with land cover and NDVI changes and implications for sustainable urban-rural development: The case of Mu Us Sandy Land, China J. Clean. Prod. 142 697-715
[9] Han J-C, Huang Y, Zhang H and Wu X 2019 Characterization of elevation and land cover dependent trends of NDVI variations in the Hexi region, northwest China J. Environ. Manage. 232 1037-1048
[10] Iwasaki Y, Tamaki T, Murata K, Koga A and Fujimoto K 2020 Detection of land cover changes before and after the 2016 Kumamoto earthquake in Japan using remote sensing for evaluation of environmental impacts. Proceedings of 2020 10th International Conference on Future Environment and Energy (ICFEE 2020) Kyoto Japan 7-9 January 2020 184-191.
[11] Agriculture land information system agriculture committee. Available online: https://www.alis-ac.jp/ (accessed on 28 January 2020).
[12] Biodiversity center of Japan. 1/25,000 vegetation survey (6th). Available online: http://gis.biodic.go.jp/webgis/sc-006.html (accessed on 31 January 2020).
[13] U.S. Geological Survey. LandsatLook Viewer. Available online: https://landsatlook.usgs.gov/ (accessed on 17 December 2019).
[14] Kimura A and Shimamura H 2015 Classification of planting condition of paddy fields utilizing two time-series acquisitions of high-resolution SAR image J. Jpn. Soc. Photogramm. Remote Sens. 54 118-132 (in Japanese with English abstract)

[15] European Space Agency. Copernicus Open Access Hub. https://scihub.copernicus.eu/ (accessed on 15 February 2020).

[16] Japan Aerospace Exploration Agency. High-Resolution Land Use and Land Cover Map of Japan (Released in September 2016/ Version 16.09). Available online: https://www.eorc.jaxa.jp/ALOS/en/lulc/lulc_index.htm (accessed on 17 February 2020).

[17] Suzuki Y, Ishimura D, Kumaki Y, Kumahara Y, Chida N, Nakata T and Nakano Y 2017 1:25,000 Active fault map Aso Geospatial Information Authority of Japan

Acknowledgments
This research was performed by the Environment Research and Technology Development Fund (JPMEERF19S20505) of the Environmental Restoration and Conservation Agency of Japan.