Detection of Land Cover Changes before and after the 2016 Kumamoto Earthquake in Japan Using Remote Sensing for Evaluation of Environmental Impacts

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Abstract. The land cover changes before and after the 2016 Kumamoto earthquake in Japan are detected using the Normalized Difference Vegetation Index (NDVI) calculated from satellite Sentinel-2A/2B images, and the methods and contents are described in this paper. The land cover change areas matched well with Google Map (aerial photographs), a high resolution latest map. In addition, the some areas where land cover changes spread over time were investigated by ground truths, and we have found that their cause is restoration works. To evaluate environmental impacts, we investigated the populations of the trapdoor spiders Heptathela higoensis in three study sites in the Aso area and Ozu Town in Kumamoto Prefecture. It is thought that the soil animal such as this spider receives the influence of the land cover changes directly. It is suggested that the changes of the spider populations can become an index to grasp the environmental changes before and after the earthquake quantitatively. The locations of the restoration works will not return to areas with high groundwater recharge capacity such as grasslands. If such restoration works spread, the people lived in the Aso and Kumamoto areas in Kumamoto Prefecture that rely on groundwater will have a serious problem in the future.

1. Introduction
First of all, overviews of the 2016 Kumamoto earthquake in Japan and the groundwater in the Kumamoto area in Kumamoto Prefecture, which are the important facts related to this study, are described below based on the information of the Cabinet Office, Government of Japan and Kumamoto City websites.

At 21:26 (JST) on April 14, 2016, a magnitude 6.5 earthquake (foreshock) occurred in the Kumamoto area in Kumamoto Prefecture located the central part of the island of Kyushu in Japan, and a seismic intensity of 7 was observed in Mashiki Town, Kamimashiki District, Kumamoto Prefecture. Furthermore, an earthquake with a magnitude of 7.3 (main shock) occurred at 1:25 (JST) on April 16, 2016, and a seismic intensity 7 was observed in Mashiki Town, Kamimashiki District and Nishihara Village, Aso District, Kumamoto Prefecture. The series of earthquakes, the foreshock and the main shock, was named “the 2016 Kumamoto earthquake” by the Japan Meteorological Agency (JMA), and caused tremendous damage to the Aso and Kumamoto areas in Kumamoto Prefecture.

Tap water of about 740,000 citizens of Kumamoto City which is the capital city of Kumamoto Prefecture is provided by 100% groundwater. In addition, the tap water of over 1 million people in Kumamoto City and its surrounding areas use mostly groundwater. Such an area where a large population relies on groundwater is rare in the world.
The Aso area has the highest groundwater recharge capacity and is an important area to maintain the quantity and quality of groundwater. The decline of groundwater recharge capacity in the Aso area will cause a serious problem. Grasslands and rice paddies have high groundwater recharge capacity. The bare lands expanded due to the landslides or slope failures, and the cracks occurred in grasslands and rice paddies. When such vegetation areas decrease and the bare lands expand, the groundwater recharge capacity deteriorates, and the groundwater quantity also decreases. We investigate the quality and quantity of spring water at several places in the Aso area [1]. There are some places where spring water is depleted or decreased after the earthquake. On the other hand, there are places where spring water is increased after the earthquake.

In this paper, the land cover changes before and after the 2016 Kumamoto earthquake in Japan are detected using satellite images, and the method and contents are described. The satellite images used in this study are Sentinel-2A/2B [2]. The land cover changes due to earthquakes can be detected as changes in the Normalized Difference Vegetation Index (NDVI). In this study, NDVI is used. This paper also describes overlay analysis using data obtained from ground truths, map information, NDVI images, satellite images, and so on.

We also investigate the transition of the populations of the trapdoor spiders Heptathela higoensis. The trapdoor spider Heptathela higoensis is a rare spider as soil animal species inside the soil at small cliffs in Japan. It is thought that the soil animal such as this spider receives the influence of the land cover changes directly. This paper presents the changes of populations of the spiders at three locations before and after the earthquake.

2. Satellites Sentinel-2A/2B and satellite image processing method

2.1. Satellites Sentinel-2A/2B

We used satellite multispectral images to detect land cover changes with NDVI. In satellite images, swath width is narrower as spatial resolution is higher. A trade-off relationship holds generally among spatial resolution, swath width, and revisit time. When the swath width is narrow, it is necessary to connect multiple images with different times. When comparing many images in time series, of course, a satellite with a short revisit time should be chosen. In this study, the land cover changes are detected, and the next step is to classify the land covers into six categories: rice paddy, crop, forest, grassland, bare land, and urban. Thus, a high spatial resolution of less than 1m is not necessary in this study.

Sentinel-2A/2B with the following features were selected because they meet the above conditions. Sentinel-2A/2B consist of two satellites, Sentinel-2A and Sentinel-2B. They are earth observation satellites developed by ESA (European Space Agency), and are effective for monitoring agriculture and environment.

1) Sentinel-2A/2B have a short revisit time of five days. There are not many opportunities to obtain good images without clouds in the observation area because optical sensor images are covered by clouds. Therefore, the higher the revisit frequency, the more advantageous.
2) The swath width is 290 km. An image obtained from Sentinel-2A/2B completely includes the Aso and Kumamoto areas, which are the observation areas of this study.
3) The spatial resolution of multispectral images in visible and near-infrared bands is 10 m, and there is no problem in the land cover classification.
4) The multispectral images can be obtained free of charge.

2.2. Our satellite image processing method

The detection method for land cover changes before and after the 2016 Kumamoto earthquake in Japan is described below.

Reference [3] extracts the landslides in the Aso and Kumamoto areas using the differences of NDVI values calculated from the images of Landsat-8 before and after the earthquake. NDVI is calculated by formula (1):

\[
NDVI = \frac{(NIR - R)}{(NIR + R)},
\]
where $NIR$ is the reflectance of near-infrared band, and $R$ is the reflectance of visible red band. NDVI represents the quantity and the activity level of vegetation, outputs the values between -1.0 and 1.0, and indicates a high value in vegetation areas. NDVI decreases when the slopes covered with trees collapse and the soil is exposed. Reference [4] also shows that the changes of NDVI are effective in detecting the slope failures caused by the earthquake using ASTER image data. Several references [5-9] describe the effectiveness of NDVI in detecting landslides or slope failures after an earthquake. The Aso area is rich in nature, and has the largest grassland in Japan. From such characteristics of the land, the damages caused by the earthquake can be regarded as the land cover change to bare land. The cracks in paddy fields and other areas can also be regarded as the land cover change to bare land. Groundwater recharge capacity is highest in grassland, and low in bare land compared with vegetation areas. The land cover changes detected with NDVI can also be examined as the decline in groundwater recharge capacity.

In this study, we used the Sentinel-2 images on March 3, 2016 before the earthquake, and the Sentinel-2 images on March 28, 2017 about one year after the earthquake, and April 7, 2019 about three years after the earthquake. NDVI images were cleated from the images, and the subtractions of two NDVI images are calculated by equation (2):

$$NDVI_{\text{sub}} = NDVI_{\text{after}} - NDVI_{\text{before}},$$

where $NDVI_{\text{sub}}$ is the subtracted image, $NDVI_{\text{after}}$ is NDVI image after the earthquake, and $NDVI_{\text{before}}$ is the NDVI image before the earthquake. Sentinel-2 was recently launched in June 2015, and the images with very few clouds before the earthquake are those on March 3, 2016. In order to avoid the seasonal variation of NDVI, we selected good images after the earthquake close to March 3.

3. Detection and analysis of land cover change areas

3.1. Overlay analysis using GIS software

In this study, overlay analyses using multiple layers are performed. We use ArcGIS Pro 2.3 and QGIS 3.6 as GIS software. The layers in ArcGIS Pro 2.3 are composed of geotagged photographs taken by the ground truths, world topographic map provided by Esri, JAXA's high-resolution land use and land cover map of Japan [10], NDVI subtracted images calculated by equation (2), NDVI images, and satellite images. JAXA's high-resolution land use and land cover map of Japan is used as the information of land cover classification, and its spatial resolution is 10 m, which is the same as the Sentinel-2 images, so it is convenient for the overlay analysis. Figure 1 shows the multiple layers in ArcGIS Pro 2.3 to employ an overlay analysis.

![Figure 1. The multiple layers in ArcGIS Pro 2.3 to employ an overlay analysis.](image-url)
Figure 2. NDVI subtracted images in a part of the Aso area.
In order to validate visually the landslide detection results, reference [11] compares the results with high-resolution DigitaGlobe images from Google Earth. We also used a similar method to do the visual validation. In ArcGIS Pro 2.3, Google Map (aerial photographs), a high resolution latest map, cannot be used as map information. Therefore, we captured Google Map (aerial photographs) into QGIS 3.6, and carried out another overlay analysis.

3.2. NDVI calculation and comparison before and after the earthquake
We describe the following two NDVI subtracted images, image 1 and image 2, calculated by equation (2) that can grasp the land cover changes about one year after and about three years after the earthquake.

- image 1: $NDVI_{after}$ (March 28, 2017) - $NDVI_{before}$ (March 3, 2016)
- image 2: $NDVI_{after}$ (April 7, 2019) - $NDVI_{before}$ (March 3, 2016)

Figures 2(a) and 2(b) show the NDVI subtracted images in a part of the Aso area, which is one of the most damaged areas by the earthquake. Figures 2(a) and 2(b) show the images 1 and 2, respectively. Figures 2(a) and 2(b) are shown in pseudo color. The stronger the red color, the higher the decrease in
NDVI compared to before the earthquake. In addition, the layers of the NDVI subtracted images and the world topographic map provided by Esri are overlapped so that the position can be understood. Figure 3 shows the location and area of Figure 2 as the black rectangle on the map of Kyushu island in Japan. The length and width of the area are 6.32km and 4.55km, respectively. Figures 2(a) and 2(b) clearly show the damages around the collapsed Aso-Ohashi Bridge by significant decreases in NDVI. The loss of vegetation has also led to a decline in groundwater recharge capacity.

In addition, the land cover change areas of image 2 was well matched when compared with Google Map (aerial photographs), a high resolution latest map.

3.3. Investigating the cause of the expansion of change areas by ground truths

Comparing figures 2(a) and 2(b), the areas where NDVI decreased spread in the image 2. The cause of this problem was investigated by ground truths at some main points.

Figure 4 is the photographs taken at three points shown by “●” around the Kyoto University Aso Volcanological Laboratory in Minamiaso Village. At these three locations, restoration works are carried out in the earthquake damage areas, so the areas where vegetation cover removed and NDVI decreased spread.

3.4. The changes of populations of the trapdoor spiders Heptathela higoensis before and after the earthquake

We investigated the populations of the trapdoor spiders Heptathela higoensis in the Aso area and Ozu Town adjacent to the Aso area. Figure 5 shows the trapdoor spider Heptathela higoensis. This spider has been listed as a vulnerable species by Ministry of the Environment, Government of Japan [12]. In three study sites, A, B, and C, shown in figure 6, the populations of the spiders were changed by the earthquake disaster. Table 1 shows the populations of the spiders in 2007, 2016, 2018 and 2019. The year 2016 in Table 1 is after the earthquake. Especially, the population of site B was sharply decreased because the damage of the earthquake was heavy in site B that was high in population density of 2007. Although the population has increased recently, it is considerably smaller than the population before the earthquake. In addition to the three study sites of the populations of the spiders, we investigate the populations in 32 study sites in the Aso area. Figure 7 shows two places where the spiders lived before the earthquake, but the spiders could not be found in 2018 and 2019. A restoration work is carried out after the earthquake in the place shown in figure 7(a). The place shown in figure 7(b) has been damaged by a slope failure due to the earthquake.

Table 1. Total number of trapdoors of Heptathela higoensis

| Study sites | 2007 | 2016 | 2018 | 2019 |
|-------------|------|------|------|------|
| A           | 157  | 0    | 2    | 3    |
| B           | 412  | 2    | 6    | 40   |
| C           | 48   | 1    | 0    | 12   |

*a Total number of trapdoors is nearly equal total number of the spiders.

Figure 5. The trapdoor spider Heptathela higoensis.
4. Conclusion
In this paper, the land cover changes before and after the 2016 Kumamoto earthquake in Japan were detected using NDVI calculated from satellite Sentinel-2A/2B images, and the methods and contents were described. It was shown that land cover changes due to the earthquake can be detected as the changes in NDVI. The land cover change areas matched well with Google Map (aerial photographs), a high resolution latest map.

In addition, the some main areas where land cover changes spread over time were investigated by ground truths, and we found that their cause is restoration works.

To evaluate environmental impacts, we investigated the quality and quantity of spring water at several places, and the populations of the trapdoor spiders *Heptathela higoensis* in three study sites in the Aso area and Ozu Town adjacent to the Aso area. Especially, it is thought that the soil animal such as the spider receives the influence of the land cover changes directly. It is suggested that the changes of spider populations are an index to grasp the environmental changes before and after the earthquake quantitatively. In addition to the three study sites of the populations of the spiders, we investigate the populations in 32 study sites in the Aso area. As a future work, we will investigate the relationship between the distribution pattern of the spiders and land cover change areas.

The locations of the restoration works investigated by the ground truths will not return to areas with high groundwater recharge capacity such as grasslands. If such restoration works spread, the people lived in the Aso and Kumamoto areas that rely on groundwater will have a serious problem in the future. Restoration works also damage the habitats of the spiders.
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