# Identifying Damaged Areas Caused by the Noto Peninsula 2024 Earthquake Using Change Detection from Optical Satellite Images

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**Abstract:**

Strategic response during disasters requires the swiftness of the flow of data and information. Simple change detections can be used from Optical Satellite Images to achieve fast results that can be used for analysis and planning. In response to the earthquake that devastated the Noto Peninsula of Japan on New Year's Day, news reports and early optical satellite images were utilized to identify areas that were damaged by the earthquake. The changes in the reflectance values and indicators, such as NDBI and NDVI were analyzed to identify the areas with damages such as collapsed buildings and landslides. From the after-event satellite images of PlanetScope and Sentinel-2, three areas were identified as severely affected based on news reports namely, Wajima City, Niemachi, and Noto Town. To verify the results of the analysis, aerial images provided by the Geographical Survey Institute of Japan, and Google Earth Street View Images were used. Through change detection methods, the locations of damaged areas were pinpointed using Optical Satellite Images after the earthquake incident.

## 1. Introduction

### 1.1 Noto Peninsula Earthquake 2024

On New Year's Day, January 1, 2024, at around 16:10 (JST) a magnitude 7.6 earthquake shook the Noto Peninsula in the Ishikawa Prefecture of Japan. The epicenter of this earthquake was located northeast of the Noto Peninsula (Japan Red Cross Society, 2024). This is the first and strongest earthquake ever recorded that hit the Noto Peninsula since 1885. (Al Jazeera, 2024) Extensive damages were reported throughout Ishikawa prefecture caused by an earthquake-induced tsunami. Ground shaking also resulted in landslides, collapsed buildings, cracked roads, and fire incidents.

### 1.2 Geotagged Areas from News Reports

The news reports from news agencies and social media websites after the disaster were collected and then geotagged. The damages were categorized into 1) tsunami damages, 2) road damage, 3) collapsed buildings, 4) landslides, and 5) fire incidents.

Figure 1. Geotagged Reports in Noto Peninsula; the numbers in the map indicate 1) tsunami damages, 2) road damages, 3) collapsed buildings, 4) landslides, and 5) fire incidents

### 1.3 Optical Satellite Images

From the geotagged reports, the available optical satellite images right after the earthquake that can be used to detect the damages brought by the earthquake were checked. Optical satellite images are images that are captured by satellite sensors using sunlight as the light source (USGS, 2016). These images are mainly used for earth observation (e.g. PlanetScope, and Sentinel-2) as they show the state of a particular area at the time of the image acquisition. This includes clouds, and shadows that may be present during the capture. The quality of information that is extracted from these images depends on the weather conditions at the time of acquisition. In this study, optical satellite images provided by PlanetScope and Sentinel-2 were used.

**1.3.1 PlanetScope Imagery:** PlanetScope's Satellite Imagery offers 8 different spectral bands, ranging from Coastal Blue to Near Infrared (NIR) having a daily revisit time. These images have a Ground Sampling Distance of about 3.7~4.2 m (Planet Labs, 2023). Due to these optimal resolutions, it was decided to use this imagery for this study. Out of the 8 bands only the Blue, Green, Red, and NIR bands were used. Surface Reflectance Difference and Normalized Difference Vegetation Index (NDVI) were calculated using these bands.

**1.3.2 Sentinel-2's Imagery:** Sentinel-2's Imagery offers 13 spectral bands ranging from Aerosol to Short Wave Infrared (SWIR) 2. The satellite has a revisit time of 5 days. The Ground Sampling Distances of these bands vary; four bands (B2, B3, B4, and B8) have 10m, six bands (B5, B6, B7, B8a, B11, and B12) have 20m, and three bands (B1, B9, and B10) have 60m (European Space Agency, 2023). The bands B11 (SWIR1) and B8a (NIR) were used to extract the Normalized Difference Built-up Index (NDBI). This index was not used using PlanetScope Imagery because SWIR1 is not included in its bands.


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### 1.4 Limitations

Due to the cloudiness of the winter season, the after-earthquake images of the affected areas were limited. Some of the areas in the news reports were either covered by clouds or were dark because of shadows. Despite this, the three areas namely, Wajima City, Niemachi, and Noto Town with visible damage were identified.

### 1.5 Change Detection

Change detection is one of the effective methods in remote sensing to detect areas in a satellite image that were altered or affected by a phenomenon (Awad and Erer, 2022). In this study, three different approaches were used to identify areas that were damaged. Surface Reflectance and NDBI changes were used to detect the damaged buildings, and NDVI changes were used to detect the landslide extent in the satellite images.

**1.5.1 Surface Reflectance Difference:** Surface reflectance is a value derived from satellite images that denote the ratio between surface radiance and surface irradiance (K C et al., 2023). This value is commonly used for change detection as it has been corrected for atmospheric effects during the time of capture of the satellite images (Hemati et al., 2021). The difference of each band (B, G, R, and NIR) of the PlanetScope Imagery between before and after the earthquake was calculated to determine the changes in surface reflectance.

**1.5.2 Normalized Difference Built-up Index:** NDBI is an index that is calculated using Equation 1 (Muhaimin et al. 2022).

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR} \quad (1)$$

where: $NDBI$ = Normalized Difference Built-up Index
$SWIR$ = Short Wave Infrared Reflectance
$NIR$ = Near Infrared Reflectance

NDBI is a remote sensing indicator that is used to detect the built-up covers in satellite images (Muhaimin et al. 2022). The value of this index ranges from -1 to 1, high positive values indicate the pixel’s likelihood to be built-up or a building. The changes in built-up cover in a particular area can be visualized by calculating the NDBI Difference between two separate dates of satellite image capture.

**1.5.3 Normalized Difference Vegetation Index:** Normalized Difference Vegetation Index (NDVI) is an index that is calculated using Equation 2 (Hartoyo et al., 2022).

$$NDVI = \frac{NIR - R}{NIR + R} \quad (2)$$

where: $NDVI$ = Normalized Difference Vegetation Index
$NIR$ = Near Infrared Reflectance
$R$ = Red Band Reflectance

NDVI is a remote sensing indicator that is used to monitor the health and changes in vegetation covers on satellite images (Hartoyo et al., 2022). This value ranges from -1 to 1, high positive values indicate the pixel’s likelihood to be vegetation. The changes in vegetation cover can be seen in an area by calculating the NDVI Difference between two separate dates of satellite image acquisition.

## 2. Methodology

The workflow of this research is shown in Figure 2 below.

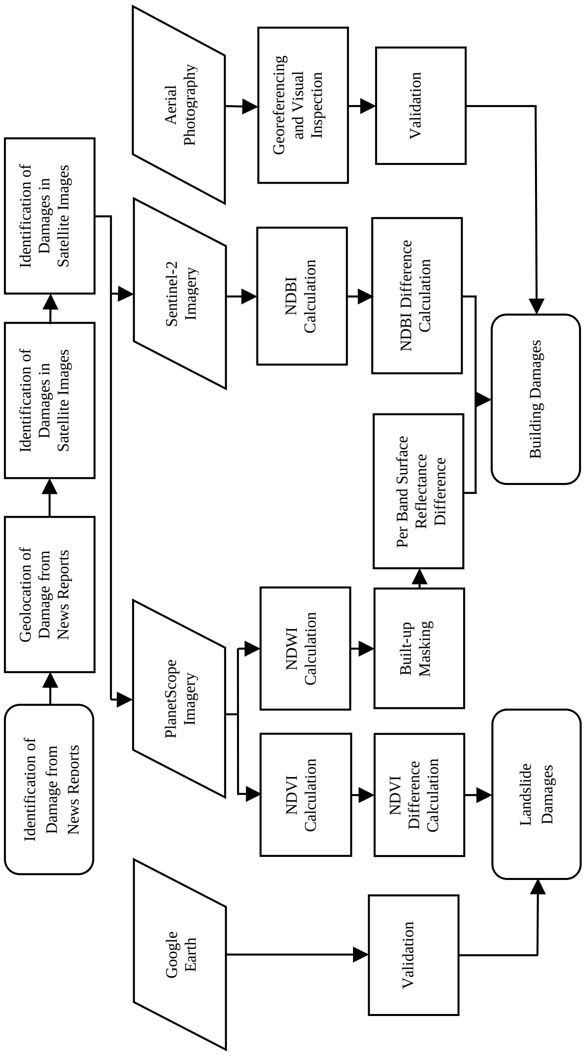


Figure 2. Research Workflow

### 2.1 Identification of Preliminary Damaged Areas

Based on the news reports that were geotagged, the satellite images from PlanetScope were inspected to see if there were visible damages that can be seen. Among these reports, the Wajima City Market Fire incident and the Niemachi Landslide were apparent in the images.

### 2.2 Selecting Satellite Images

After the preliminary inspection, the images that were selected were acquired closest to the date of the disaster. For the Wajima City Market Fire incident, Figure 3, the earliest available date after the earthquake was on January 2, 2024. For the Niemachi landslide, Figure 4, the earliest date of capture was on January 5, 2024. Additionally, while looking for damages around the prefecture, a possible landslide area was also located in the northeast part of Noto Town, Figure 5. The date of this image was January 2, 2024.

Figure 3. Wajima City (PlanetScope, 2 Jan. 2024)

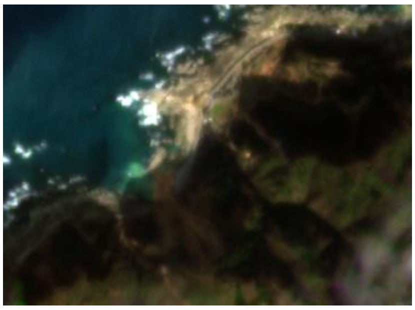

Figure 4. Niemachi (PlanetScope, 5 Jan. 2024)

Figure 5. Noto (PlanetScope, 2 Jan. 2024)

In selecting the before-the-earthquake satellite images, the images that had almost the same weather conditions and time of acquisition as near as possible were chosen. Some images in late December 2023 with snow were disregarded. Images in late November and early December 2023 were opted for. The following figures (Figures 6 to 8) show the areas and acquisition dates.

Figure 6. Wajima City (PlanetScope, 3 Nov. 2023)

Figure 7. Niemachi (PlanetScope, 1 Nov. 2023)

Figure 8. Noto (PlanetScope, 6 Dec. 2023)

To better understand the changes that happened in the built-up of Wajima City, Sentinel-2 Imagery of the Copernicus Programme of the European Union Space Programme was included as it has the Short Wave Infrared Band that can be used to calculate the NDBI. The after-the-earthquake images available for Wajima City in the Sentinel-2 Imagery were on January 5, 2024, and the previous image was from November 21, 2023. The southern part of Wajima City was cloudy during the time of the capture, but the majority of the city in the January 2024 image was still visible.

### 2.3 Building Damage Detection

To detect the building damages that happened in Wajima City, images from PlanetScope and Sentinel-2 were used. The before and after earthquake images of the area of interest were compared to see the significant changes. The reflectance differences per band in the Visible (Blue, Green, and Red) and NIR regions were calculated using the PlanetScope Imagery. The difference in NDBI using the Sentinel-2 Imagery was calculated.

**2.3.1 Masking:** To enhance the analysis of the built-ups, a built-up mask using NDVI and Normalized Difference Water Index (NDWI) was applied. Using only NDVI as a criterion for the mask was not enough to highlight the built-up cover in the area of interest in Wajima City as the low values of NDVI included some pixels in the water bodies of the city. Therefore, the NDWI was included in the criteria for the mask. The NDWI is calculated using Equation 3 (Ihsan et al., 2023).

$$NDWI = \frac{G - NIR}{G + NIR} \quad (3)$$

where: $NDWI$ = Normalized Difference Water Index
$G$ = Green Band Reflectance
$NIR$ = Near Infrared Reflectance

NDWI is a remote sensing indicator that is used to detect the presence of water bodies in a satellite image (Ihsan et al., 2023). This value ranges from -1 to 1, high positive values indicate the pixel's likelihood to be a water body.

Through trial and error, built-ups were narrowed down to have an NDVI value of less than or equal to 0.35 and an NDWI value of less than or equal to 0.05.

**2.3.2 Band Reflectance Value Difference for Built-ups:** Using PlanetScope Imagery, the reflectance value differences in the Blue, Green, Red, and NIR Bands were calculated. The difference in reflectance value was calculated using Equation 4.

$$Reflectance\ Difference = P_{ref} - C_{ref} \tag{4}$$

where: $P_{ref}$ = Previous Reflectance
$C_{ref}$ = Current Reflectance

**2.3.3 NDBI Difference for Building Damage:** Sentinel-2 Imagery was used to calculate the previous and current NDBI in Wajima City. NDBI Difference is calculated using Equation 5 below.

$$NDBI\ Difference = P_{NDBI} - C_{NDBI} \tag{5}$$

where: $P_{NDBI}$ = Previous NDBI
$C_{NDBI}$ = Current NDBI

High difference values indicate a change in the built-up cover in an image.

### 2.4 NDVI Difference for Landslide

One of the indicators of landslides in a vegetated area is a sudden decrease in NDVI value (Teo and Wen, 2022). The NDVI Difference from PlanetScope Images was extracted using Equation 6.

$$NDVI\ Difference = P_{NDVI} - C_{NDVI} \tag{6}$$

where: $P_{NDVI}$ = Previous NDVI
$C_{NDVI}$ = Current NDVI

High difference values indicate a change in the vegetation cover in an image.

### 2.5 Validation

**2.5.1 Aerial Photograph:** Geographical Survey Institute of Japan (GSI) through the National Land Image Information (Color Aerial Photographs) of the Ministry of Land, Infrastructure, Transport and Tourism, published an aerial photograph of Wajima City captured last January 5, 2024, the same date as the Sentinel-2 Image. This aerial photograph from GSI was georeferenced to better see the damages as it has better spatial resolution than the satellite images. The aerial photograph as seen in Figure 9 covered the northern parts of Wajima City. In this aerial photograph, some damaged buildings that were not visible in the optical satellite images were seen.

Figure 9. Aerial Image of Wajima City – January 5, 2024 (GSI, 2024)

**2.5.2 Google Earth Street View Images:** Street-view images in Google Earth provide users with a 3D view of an area in a particular location on the map. A street-view image of the Niemachi Landslide was uploaded to Google Earth Pro in February 2024 by a user named Noriyasu Obushi. In these street view images, the landslides in Niemachi can be seen. The locations of these landslide areas were cross-referenced to the areas that were identified after processing the satellite images.

## 3. Results and Discussion

### 3.1 Per Band Surface Reflectance Difference Maps

**3.1.1 Built-up Masking:** The Surface Reflectance Difference of the Visible (B, G, and R) and NIR bands of PlanetScope was calculated to understand the changes that occurred in the surface reflectance values.

Figures 10 and 11 show the result of the masking threshold (NDVI of less than 0.35 and NDWI value of less than 0.05) in the satellite images. As seen from these two images, the majority of the built-ups in Wajima City were included in the mask.

Figure 10. Built-up Mask for November 3, 2023

Figure 11. Built-up Mask for January 2, 2024

Figure 12 shows the histogram of the masked built-ups in Wajima City on November 3, 2023, and January 2, 2024. The histogram graph reflects the distribution of pixel values in an image; the x-axis corresponds to the pixel value and the y-axis reflects the frequency or the number of pixels with a certain pixel value. The comparison between the histograms suggests that there were slight changes in the frequency and values in the Blue, Green, and Red bands. The majority of the pixel values are still within 0-2000. A slight change in the frequency is observed. While in NIR, there is a significant increase in the frequency of pixels with values ranging from 0 to 2000. The base map used to illustrate the following maps is Google Satellite Images from the QuickMapServices Plugin of Quantum Geographic Information System.

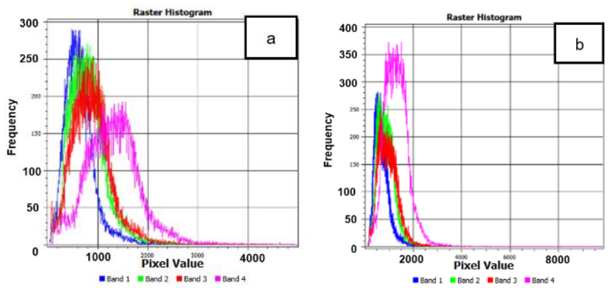


Figure 12. Histogram (a) Nov 2023 vs (b) Jan 2024

Figures 13, 14, 15, and 16 show the maps of the difference and their corresponding histograms in Blue, Green, Red, and NIR bands respectively. The y-axis in these graphs represents the frequency of the pixel values, and the x-axis represents the pixel values. Based on these maps and their corresponding histograms, there is no significant change in the reflectance of the Visible (B, G, R) and NIR bands as the peak of the pixel values in the graph can be found near 0.

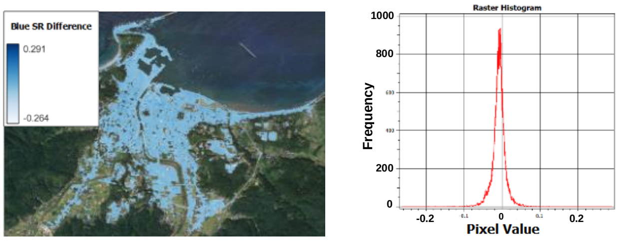


Figure 13. Blue Reflectance Difference and Histogram

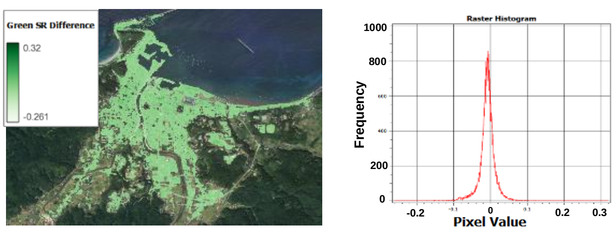


Figure 14. Green Reflectance Difference and Histogram

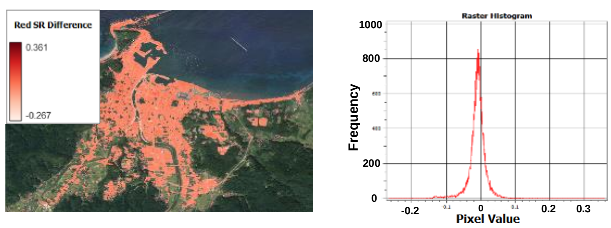


Figure 15. Red Reflectance Difference and Histogram

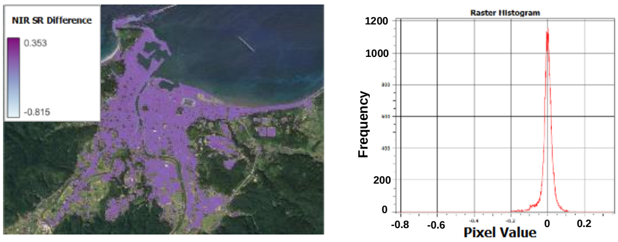


Figure 16. NIR Reflectance Difference and Histogram

The significant increase in the frequency of pixels with NIR values ranging from 0 to 2000 is due to the sediments that accumulate in the river and on the coastline. Figure 17 shows the NIR difference maps that highlight the positive and negative NIR differences in Wajima City. The purple area indicates the areas with positive difference values indicating a decrease in NIR value while the white area indicates the areas with negative difference values which indicate an increase in NIR Value. The areas with white colors are found along some of the damaged areas and in the river and coastal areas where the suspended materials have settled.

Figure 17. NIR Reflectance Difference Map

The areas where there is a high difference in reflectance were found near and within the area where the Wajima City Market fire incident occurred as seen in Figure 18**.**

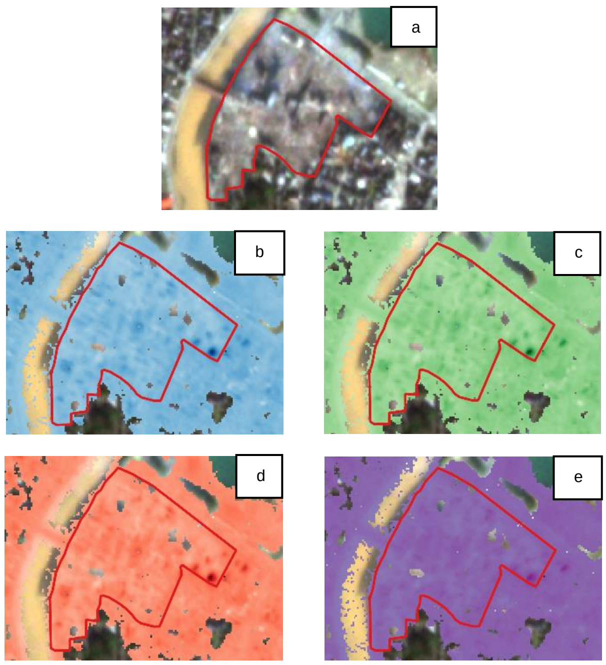


Figure 18. Zoomed-in Images of Wajima City Market in (a) True Color, (b) Blue Band Difference, (c) Green Band Difference, (d) Red Band Difference, and (e) NIR Band Difference; the red polygons indicate the areas where the fire incident occurred

### 3.2 NDBI Difference

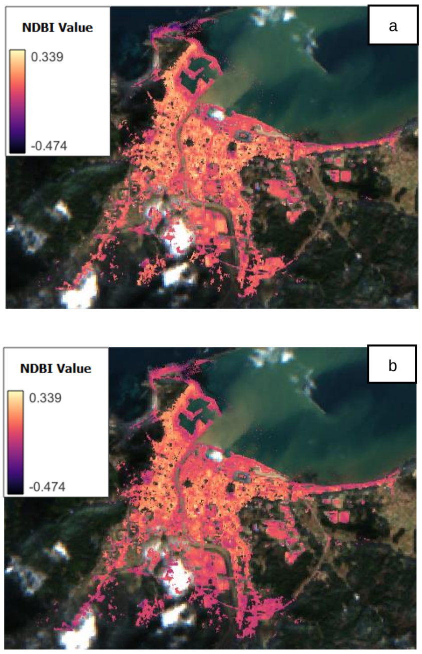


Figure 19. NDBI of Wajima City on (a) November 2023 vs. (b) January 2024

Figure 19 shows the NDBI of Wajima City calculated from the Sentinel-2 Imagery from November 21, 2023 (19a) and January 5, 2024 (19b). The values in these maps range from -0.474 to 0.339.

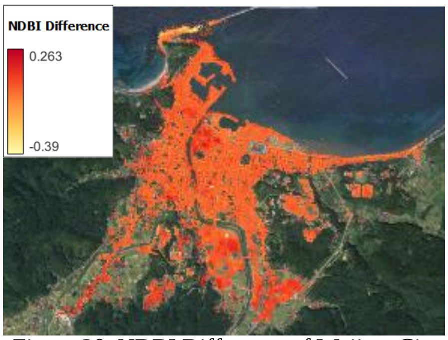


Figure 20. NDBI Difference of Wajima City

Figure 20 shows the NDBI Difference of Wajima City in the Sentinel-2 Images. The value in this map ranges from -0.390 to 0.263. The red areas show a positive change in that area which indicates a decrease in NDBI value which could mean a degradation in the built-up cover. The most prominent area with a high NDBI Difference is where the Wajima City Market Fire occurred as seen in Figure 21 highlighted with the blue polygon.

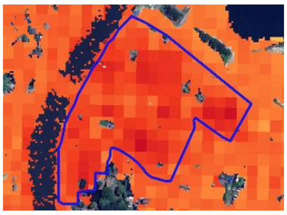

Figure 21. NDBI Difference of Wajima City Market

There are some notable areas around the southern part of the city with a high concentration of red pixels, but upon closer inspection of the satellite images, these high-value differences in the pixels are caused by clouds and shadows.

Using the NDBI Difference Map as a reference, other areas with high difference values (dark red pixels) were checked if these areas indicative of damaged structures in the aerial photograph.

Figure 22 shows the areas in the aerial photograph with damaged buildings and their corresponding pixels with NDBI differences. These pixels with high positive values in the NDBI difference correctly identified the areas with damaged buildings in Wajima City. The NDBI Difference of the pixels identified to be damaged buildings ranges from 0.065 to 0.22.

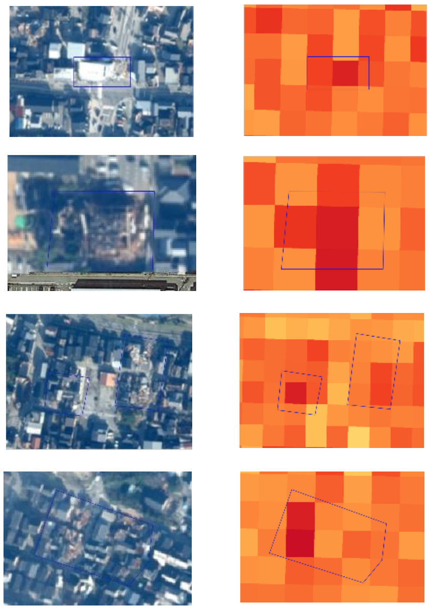

Figure 22. Damaged structures in Wajima City with corresponding NDBI difference pixels; the blue polygons indicate the damaged areas

**3.3.1 Wajima City Market Fire Surviving Buildings:** From the aerial photograph of Wajima City, some buildings were still standing within the area where the fire incident occurred, see Figure 23a. These buildings were digitized to see their corresponding values in the NDBI Difference Map. Figure 23b, shows the outline of the buildings overlapped in the NDBI Difference Map. The standing buildings were not found in the deep red pixels with higher positive values. Even so, the pixels still have positive differences indicating a degradation of the buildings.

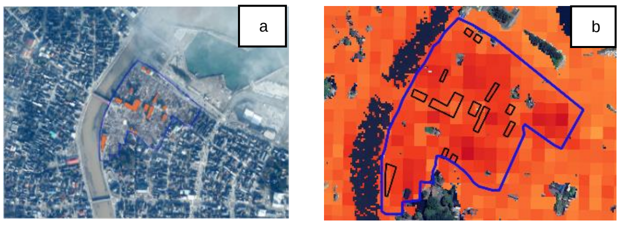


Figure 23. Standing Buildings in Wajima City Market (a) Digitized and (b) overlapped in NDBI Difference Map

### 3.4 NDVI Landslide Map

Figures 24a and 24b show the images before and after the landslide that devastated Niemachi in Suzu, respectively. Figures

25a and 25b show the NDVI of these two scenarios. It can be seen in Figure 25b the two areas where the NDVI value suddenly dropped. Figure 26 shows the NDVI Difference Map of the area, where these two areas indicate a decrease in NDVI value. These areas are where the landslides from news reports occurred.

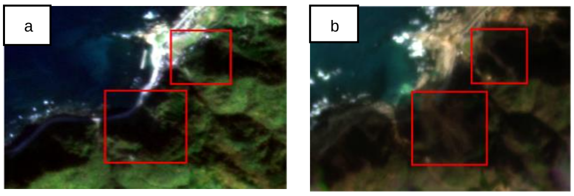


Figure 24. PlanetScope Images of Niemachi on (a) November 1, 2023, and (b) January 5, 2024; the red boxes indicate the damaged areas

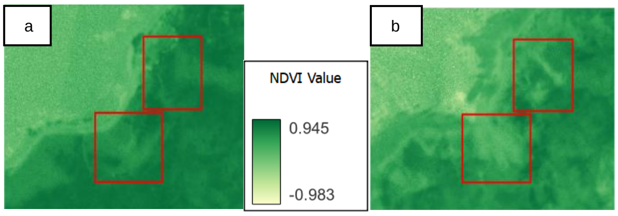


Figure 25. NDVI of Niemachi on (a) November 1, 2023, and (b) January 5, 2024; the red boxes indicate the damaged areas

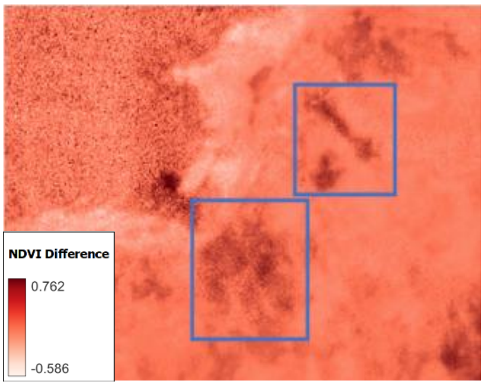


Figure 26. NDVI Difference Map of Niemachi; the blue boxes indicate the damaged areas

Figure 27 shows the landslide that covered the entire road in Niemachi. Figure 28 shows the landslide that occurred in a residential area. The houses that were buried under the rubble caused by the landslide are visible in this Google Street View Image and also on news reports (NHK, 2024). The NDVI Difference of the pixels identified as a landslide ranges from 0.3 to 0.56.

Figure 27. Niemachi Landslide covering a road seen on Google Earth (N. Obushi, 2024)

Figure 28. Landslide on a residential area seen on Google Earth (N. Obushi, 2024)

### 3.5 Possible Landslide in Noto

Figure 29 shows the PlanetScope image of Noto Town last January 2, 2024. Figures 30a and 30b show the before and after images of the area where the suspected landslide occurred, respectively. Figures 31a and 31b are the NDVI maps of the same area before and after the earthquake. It shows a decline in NDVI values in the suspected landslide area. Highlighted in the red boxes within the images is the possible landslide area that were identified. Figure 32 shows the NDVI Difference Map of the area. Highlighted with a blue polygon, the area has a very high value of NDVI difference that indicates a sudden change in vegetation cover caused by a landslide. The NDVI Difference of the pixels suspected to be a landslide ranges from 0.25 to 0.35.

Figure 29. PlanetScope Image of Noto – January 2024; the red box indicates the damaged areas

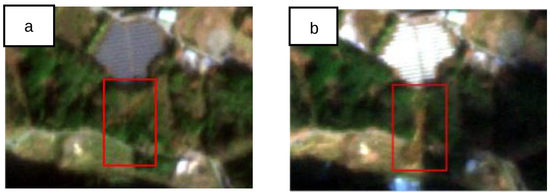


Figure 30. Possible Landslide Area in Noto (a) December 8, 2023, and (b) January 2, 2024; the red boxes indicate the damaged areas

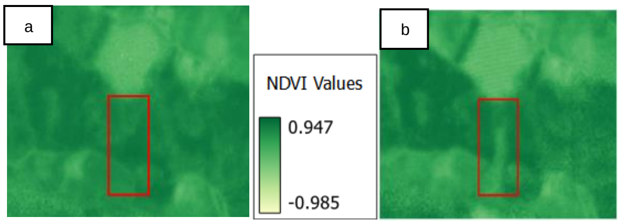


Figure 31. NDVI Map of the Landslide Area in Noto (a) December 8, 2023, and (b) January 2, 2024; the red boxes indicate the damaged areas

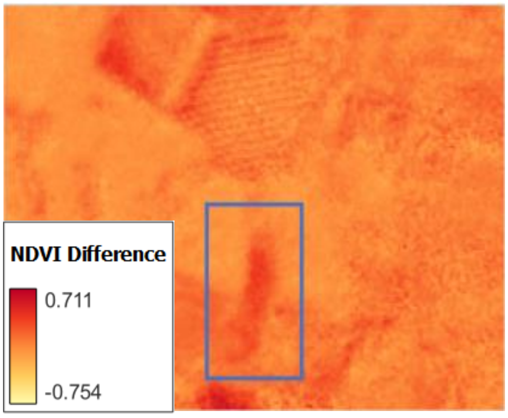


Figure 32. NDVI Difference Map of the landslide area in Noto; the blue box indicates the damaged area

## 4. Conclusion and Recommendations

By using NDBI differences from optical satellite images, possible building damages caused by disasters can be identified. The use of NDVI differences can detect landslide-affected areas. Using only per band Surface Reflectance Difference is not enough to detect the effects of disasters compared to using remote sensing indicators. It is recommended to have a training model that has more historical data to accurately assess the changes. It is also recommended to conduct actual ground verification for the detected changes. However, these rapid and simple change detections using said indicators are useful to detect damages within areas that greatly need immediate emergency response during disasters.

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