Monitoring the Recovery of the Tsunami Damaged Areas using Satellite Observation and Field Survey for Environmental Education

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Abstract: Remote Sensing is a powerful technology for monitoring the damages of disasters. On March 11, 2011, the Great East Japan Earthquake struck Tohoku Region of Japan. Huge area in the northeast coast of Japan was seriously damaged by the magnitude 9.0 earthquake and subsequent tsunami. Since then, the authors have been monitoring the environment recovery of the damaged areas in the Miyagi Prefecture with satellite images and field survey for over 10 years. As for the ground survey, we have selected some areas for fixed point observation. University students and local high school students were involved in the field survey. The main objective of this project is to promote the environmental education by connecting satellite images with onsite photos. The result suggested that the time series comparison of satellite images and onsite photos was quite useful for the education of understanding the environment recovery of the of damaged areas.

Keywords: Earth Environment, the Great East Japan Earthquake, Tohoku Area

1. INTRODUCTION

On March 11, 2011, Great East Japan Earthquake with a magnitude of 9.0 struck Tohoku Region of Japan. Huge area along the coast of the northeast Japan was seriously damages by the earthquake and subsequent tsunami. Figure 1 shows the epicenter and the seismic intensity distribution of the earthquake (JMA, 2011). The maximum height of tsunami was 9.3m recorded in Soma, Fukushima (See Figure 2). Total of 561 sq. km was inundated by the tsunami (Nagayama et. al., 2011). More than 15,800 people were dead and more than 2500 people are still missing (NPA, 2015). At that time, more than 5000 satellite images were taken within two weeks after the disaster under the international cooperation (Takahashi et. al., 2012). The comparison of the satellite images taken before and after the disaster enhanced the serious damages of the area. At that time, the authors decided to set up a project to utilize satellite images for monitoring the recovery of the damaged areas by comparing with field survey under the cooperation with university students and high school students. The main objective the project was to promote environmental education with remote sensing. This project was supported by JSPS KAKENHI Grant Number JP90256199(2012-2016) and JP17H01983(2017-2021) for total of 10 years. This paper summarizes the outcome of the project.

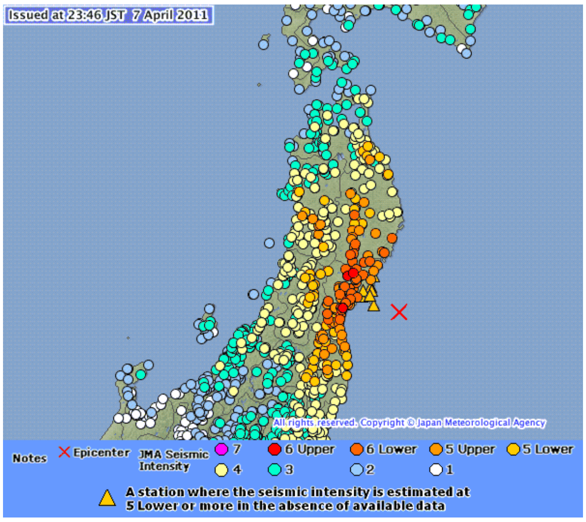


Figure 1. Epicenter & seismic intensity distribution of the Japan Earthquake (Mar. 11, 2011, JMA)

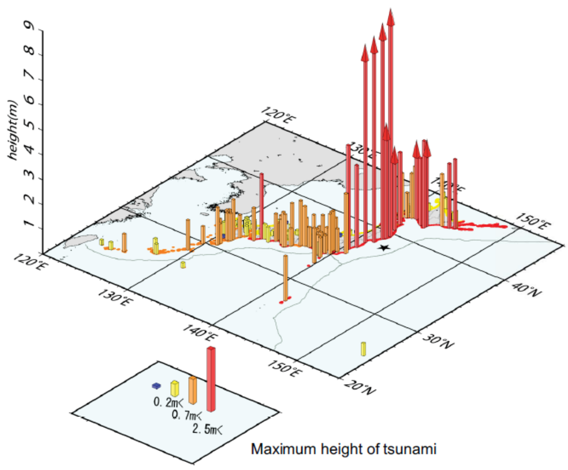


Figure 2. Observed maximum hight of tsunami (Mar. 11, 2011, JMA)

2. MONITORING SITES

Following the approval of this project by JSPS in 2012, the authors visited Miyagi Prefecture in June 2012 and performed preliminary survey to decide the continuous monitoring sites. Since the main purpose of the project was to perform environmental education, the authors decided to involve not only our university students but also students from the local high schools. Sendai Technical High School and Kesennuma-Kouyou High School kindly agreed to cooperate with us. Considering the damages and accessibility from the high schools, the authors have selected Kesennuma City, Minamisanriku Town, Kitakami River, Ishinomaki City, Wakabayashi-ku and Yuriage Area as monitoring sites as shown on Figure 3. All of the areas were seriously damaged by the tsunami.

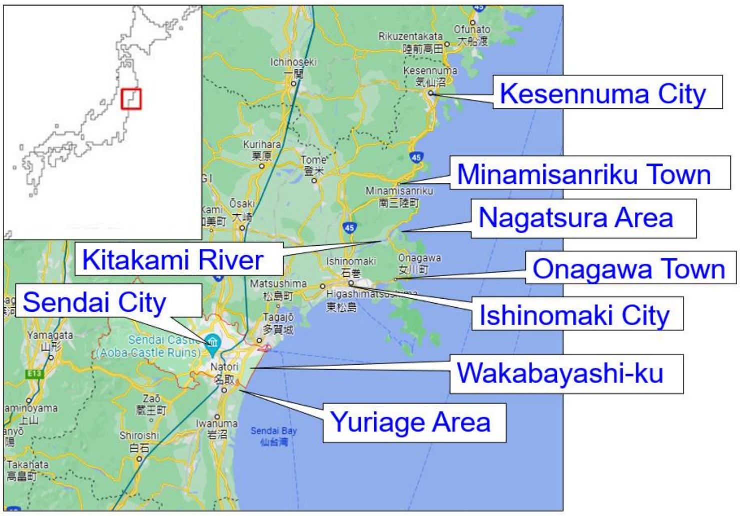


Figure 3. Monitoring sites

3. METHODOLOGY

Figure 4 shows the conceptual diagram of the project. The project went on in the following procedure.

(1) Education of students on remote sensing
(2) Continuous field survey at monitoring sites
(3) Recovery monitoring using satellite mages
(4) Development of educational materials
(5) Information dissemination on environmental recovery

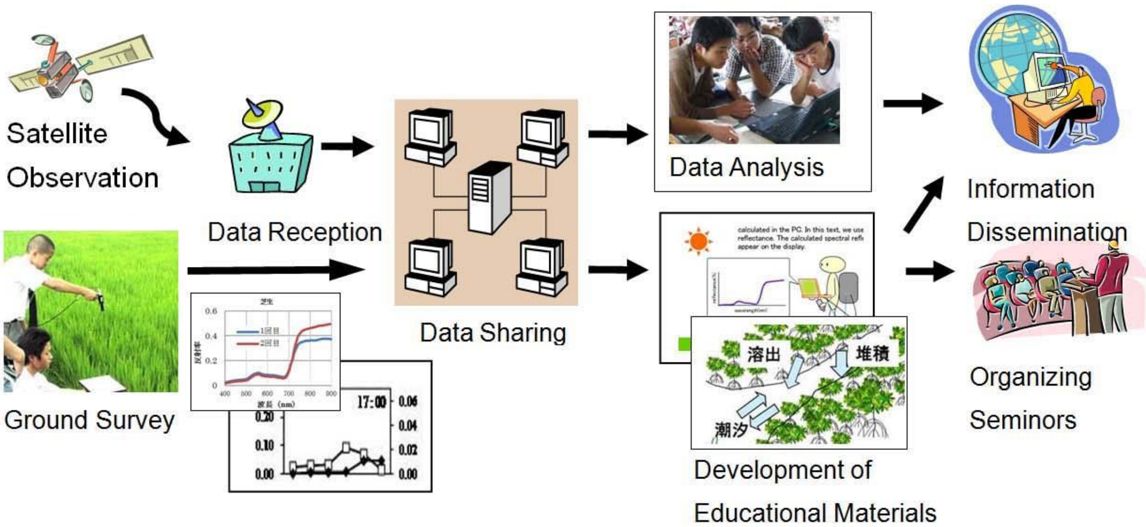


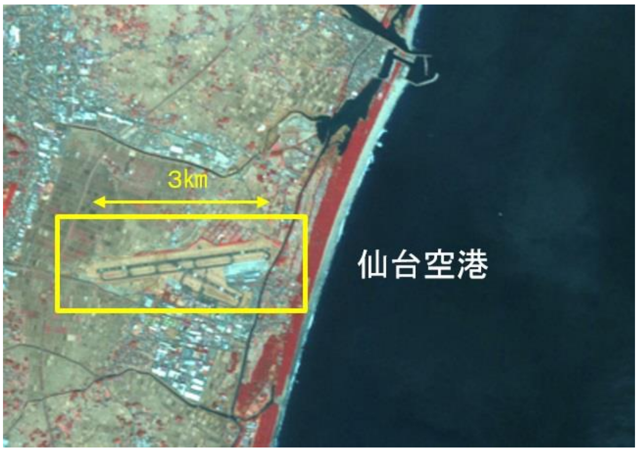
Figure 4. Conceptual diagram of the Project

3.1 EDUCATION OF STUDENTS ON REMOTE SENSING

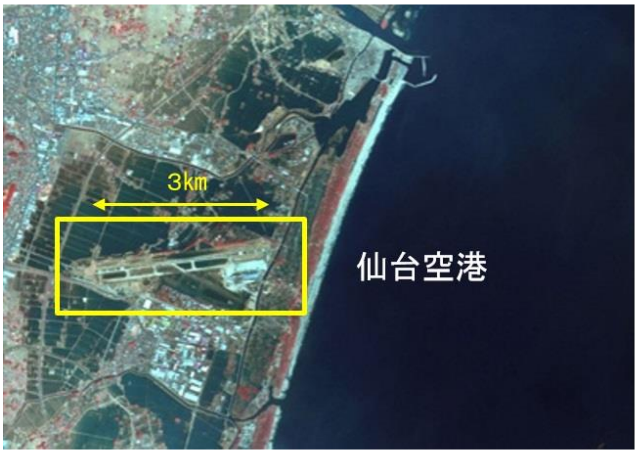
Before starting the field survey with students, the authors gave lectures on remote sensing to the high school students. Kesennuma-Kouyou High School located in Kesennuma City was seriously damaged by the tsunami associated with the earthquake on March 11, 2011. The tsunami went up to the fourth floor of the high school building (see Figure 5). Though over 1200 citizens of the city lost their lives in the tsunami, because of the rapid evacuation, no one lost their lives at the high school. The lectures was given in a classroom of the prefabricated housing build on the hillside of the city (see Figure 6). The authors explained the concept of remote sensing and how the tsunami damages are observed in satellite images. Various satellite images of Miyagi Prefecture taken before and after the tsunami were presented at the lecture. Figure 7 show such an example. By putting the scale in the images and providing aerial photo of the area was quite effective for the high school students to realize the scale of the tsunami. The students did experience the tsunami by themselves. However, they were quite shocked to see the tsunami invading huge area of Miyagi Prefecture in satellite images and aerial photos. This experience gave strong motivations to the students to do the field survey to monitor the recovery of the damages areas by comparing the onsite photos with satellite images.

Figure 5. Outlook of Kesennuma-Kouyou High School after the tsunami.

Figure 6. Remote sensing lecture given in the classroom of prefabricated housing build on the hillside.



(a) ALOS/AVNIR2 image (Feb.27, 2011)



(b) ALOS/AVNIR2 image (Mar. 14, 2011)

(c) Aerial photo (Mar. 11, 2011)

Figure 7. Comparison of ALOS/AVNIR2 images and an aerial photo of Sendai Airport
(ALOS images ©JAXA, Aerial photo: ©Japan Coast Guard)

3.2 CONTINUOUS FIELD SURVAY AT MONITORING SITES

The field survey was performed almost every six months by taking photos at several fixed points of the monitoring sites as shown on Figure 3. Measurement of salinity of soil and water quality were also performed occasionally. However, in this paper, the discussion will be focused on taking time series of onsite photos for environmental recovery monitoring.

(1) Difficulty of taking fixed point photos

In initial stage of the field survey, the authors just plotted the fixed points on maps to take images at the same location every time the authors and students visit the monitoring sites. However, taking the images of same area from the fixed point with fixed direction was not easy. GPS camera accuracy is around 10m, which is not so reliable. Because of the reconstruction work, the scenery of the disaster-damaged areas dramatically changed from time to time. Figure 8 shows an example of such a case. The photos were taken with 4 months interval in Nagatsura Area located at the mouth of Kitakami River. They do not look like the same location. The damaged houses which were captured in the photo (Figure 8(a)) taken on June 2, 2012 were not existing in the photo (Figure 8(b)) taken on October 14, 2012. In this case, finally, the authors identified the location by looking the shape of hills in the background. Sometimes, due to the reconstruction of the area, entering to the location of the fixed point were not allowed. Figure 9 shows another example photos taken on the street of Nishiki-cho, Kesennuma City. They were taken from "a fixed point". However, due to the difficulty of identifying the fixed point, the position and frame size of each photo are not the same.

(a) June 2, 2012 **(b) October 14, 2012**

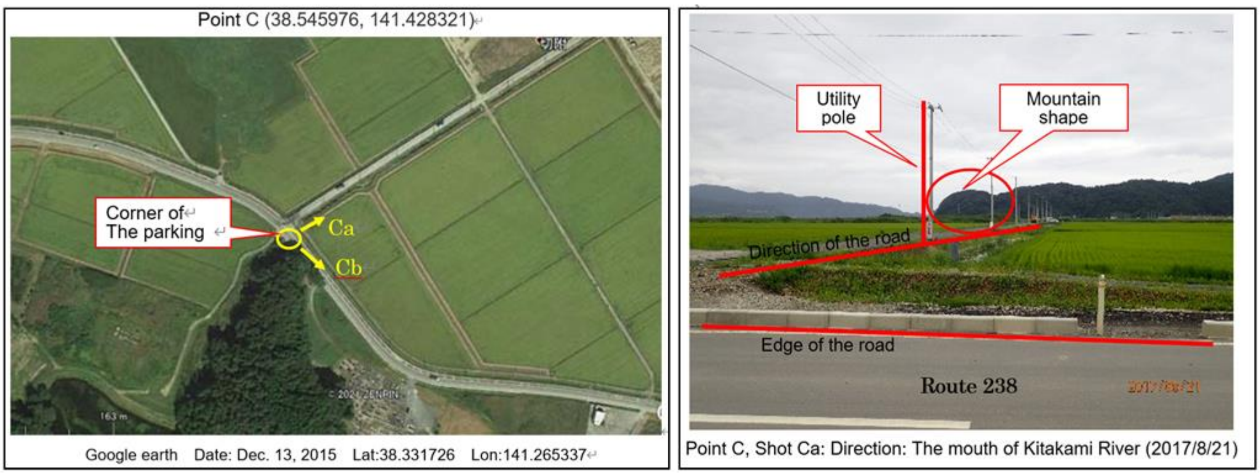
Figure 8. examples of fixed point photos (Nagatsura District, Ishinomaki City)

(a) December 13, 2011 **(b) October 14, 2012** **(c) March 21, 2013** **(d) August 23, 2013**

Figure 9. Examples of "a fixed point" photos taken on the street of Nishiki-cho, Kesennuma City.

(2) Preparation of manual of taking fixed point photos.

After some experiences, the authors have decided to make a manual for taking fix point photos as shown on Figure 10. The fixed points were plotted on the Google Earth with direction of taking photos. In addition, the photo taken at the last field survey was printed with check points of the scenery such as mountain shape, utility pole, guardrail, direction of roads etc.



(a) Fixed point plotted on the Google Earth. **(b) Latest photo and check points of the scenery.**

Figure 10. Example of the manual of taking fixed point photos

(3) Development of the Time Shift Monitor

The manual of taking photos from fixed points were quite useful. However, it was still not so easy to adjust the frame of the camera to the previous photos printed in the Manual. To improve the time series adjustment of fixed point photos, the authors have developed a software call "Time Shift Monitor" which runs on a iPad Pro for capturing the time series of fix point photos. Table 1 show the hardware specification of Time Shift Monitor, and followings are the basic functions of the software.

-Display function of location and direction of photos taken in the past.

The location and direction of photos taken is the past will be overlayed on a map or on an aerial photo as shown on Figure 11. Blue arrows show the location and direction of the archived photos and red arrow shows the current location and direction of the terminal. By moving to the blue arrow, the operator can take photo from almost the same position with the archived photo.

Table 1. Hardware specification of Time Shift Monitor

Model	Apple iPad Pro (2018)
Type	Tablet terminal
O S	iOS14
Size	11.05 x 8.46 x 0.25 in
Resolution	2,224×1,668
Sensors	GNSS ： GPS , GLONASS , GALLILEO Digital compass accelerometer, gyro
Camera	12M pixels
remarks	Google Map SDK available WiFi rooter Luminance：600nt

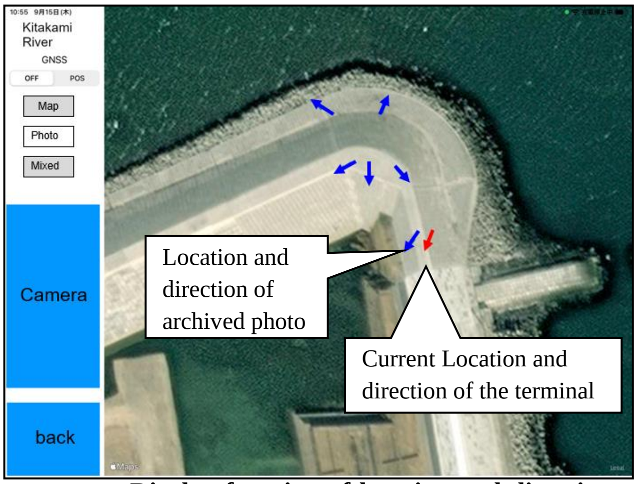


Figure 11. Display function of location and direction of photos taken in the past.

-Overlay function of archived photo with current view.

By clicking the blue allow as shown on Figure 11, the archived photo taken at the location will be displayed on the terminal. Then, by moving the slide button on the screen, one can overlay the current view of the terminal camera as shown on Figure 12. By moving the attitude of the terminal (See Figure 13), one can adjust the landscape of the archived photo with the real view of the camera, and one can take a photo at almost same angle with the archived photo.

Figure 12. Overlay function of archived photo with current view.

Figure 13. Taking a photo with the Time Shift Monitor

-Capture and recoding functions.

By pushing the capture button, the image is recorded in the terminal with location and direction information. The time shift monitor is a powerful tool for taking photos for recording time series of fixed point monitoring.

(4) Environmental education through the field survey

After viewing various satellite images of the damaged areas, university and high school students were involved in the field survey as shown on Figure 14. By comparing with satellite images, the student could understand the scale of the damages derived by the Tsunami. Most of the students were quite shocked with the serious damages of the monitoring sites.

(a) Taking photos **(b) Comparison with satellite images** **(c) Soil Salinity measurement** **(d) Discussion**

Figure 14. Field survey by the students

Taking fixed point photos was useful for the students to recognizing the steady environmental recovery of the damaged areas. Figure 15 show the time series of photo of break water reconstruction at the seaside of Higashi-matsuyama City.

(a) June, 2 2012 **(b) Mar. 10, 2014** **(c) Aug. 22, 2015** **(d) Aug.23, 2016** **(e) Mar. 9, 2017**

Figure 15. Reconstruction of the break water at the sea side of Higashi-matsuyama City.

Figure 16 show the time series of photo of the bay side of Onagawa Town. The green part of the building in Figure (a) and (b) is the roof top of a building which was overturned by the tsunami. New construction of buildings in this area was prohibited after the tsunami.

(a) Dec. 13, 2011 **(b) Aug. 23, 2014** **(c) Mar. 8, 2015** **(d) Mar. 8, 2018** **(e) Mar. 9, 2019**

Figure 16. Reconstruction of the bay side of Onagawa Town

3.3 RECOVERY MONITORING USING SATELLITE IMAGES

(1) Time series comparison of satellite images

Time series of various satellite images were collected to monitor the recovery of the damaged areas. In this section, time series of satellite images of Kitakami River are presented to see how the environmental recovery of the damaged areas could be observed with satellite images.

Kitakami River is the largest river in the Tohoku region, the northern part of Japan. The source of the river is in northern part of Iwate Prefecture, and it flows down to south to Miyagi Prefecture. It has two mouths, one faces to Ishinomaki Bay and the other faces to the Pacific Ocean. On March 11, 2011, the tsunami struck the latter mouth of the river and gave serious damage to the region. The Tsunami went up the river for 49km. Huge agricultural fields along the river were inundated by the tsunami. Figure 17 show the aerial photos taken before and after the tsunami. 224ha of agricultural field was destroyed and inundated by the tsunami. Figure 18 show time series of satellite images near the mouth of Kitakami River from 2011 to 2017. The construction of breakwater was completed in January 2017. The steady land reclamation and recovery of the agricultural field can clearly be seen from these images. Figure 19 show the high resolution satellite images of the reclaimed area taken in 2010(before), 2011(after) and 2020. From these images, we can understand that the seriously damages agricultural field of this area was reconstructed within 10 years.

(a) Before the Tsunami (Jul. 1995) (b) After the Tsunami (Apr. 5, 2011)

Figure 17. Aerial photos of the mouth of Kitakami River taken before and after the Tsunami

(a) Jan. 16, 2011 (ASTER) (b) Mar. 19, 2011 (ASTER) (c) Jun. 27, 2012 (ASTER)

(d) Apr. 25, 2015 (OLI) (e) Aug. 6, 2015 (OLI) (f) Apr. 5, 2017 (OLI)

Figure 18. Time series of satellite images of the mouth of Kitakami River taken before and after the Tsunami

(a) Jun. 25, 2010 (GeoEye-1) (b) Mar. 14, 2011 (WorldView-1) (c) Nov. 15, 2020 (WorldView-2)

Figure 19. High resolution satellite images of the mouth of Kitakami River reflecting the recovery of the area.

(2) Utilizing NDVI for monitoring the recovery of paddy fields

NDVI (Normalized Difference Vegetation Index) defined by the following formula is a typical index for estimating the condition of vegetation (Weier et al., 2000).

$$NDVI = (NIR - VIS)/(NIR + VIS) \qquad (1)$$

where NIR: Near infrared band (MODIS band 2)
VIS: Visible red band (MODIS band 1)

Since near infrared portion of the spectrum is quite sensitive to water, the existence of water dramatically reduces the reflectance of a target area. Thus, the NDVI is likely to decline in inundated area. The 16 days composite of MODIS NDVI dataset provided by NASA (MOD13Q1, 2017) was analyzed in this study to evaluate the recovery of paddy field damaged by the Tsunami. Figure 20 shows a part of the agricultural recovery map of the Sendai Area prepared by the Government of Miyagi Prefectural (2015). Yellow area(hereafter referred to as Area-A) corresponds to the area where the recovery project started in 2011, green area(hereafter referred to as Area-B) started in 2012, and purple area(hereafter referred to as Area-C) started in 2013. It is clear that the agricultural recovery project started from the inland area where the damages of the Tsunami was lighter than inshore area. Then the recovery project was expanded toward the inshore area. The authors have selected two test areas from the three coloured areas as shown on Figure 20. ● show test areas selected in the recovery project area started in 2012. ● show test areas selected in the recovery project area started in 2012, and ● show test areas selected in the recovery project area started in 2013.

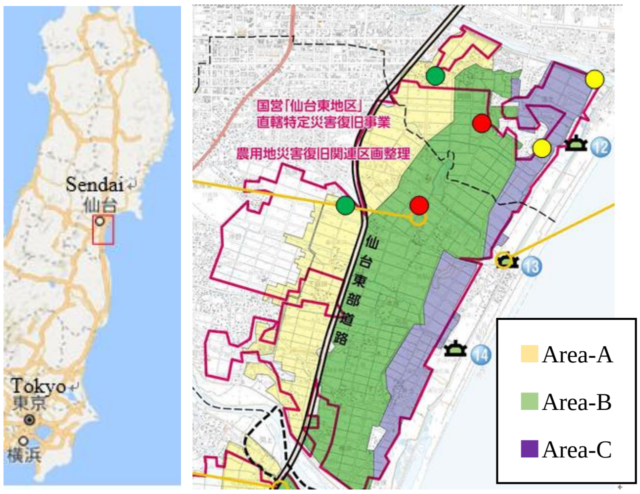
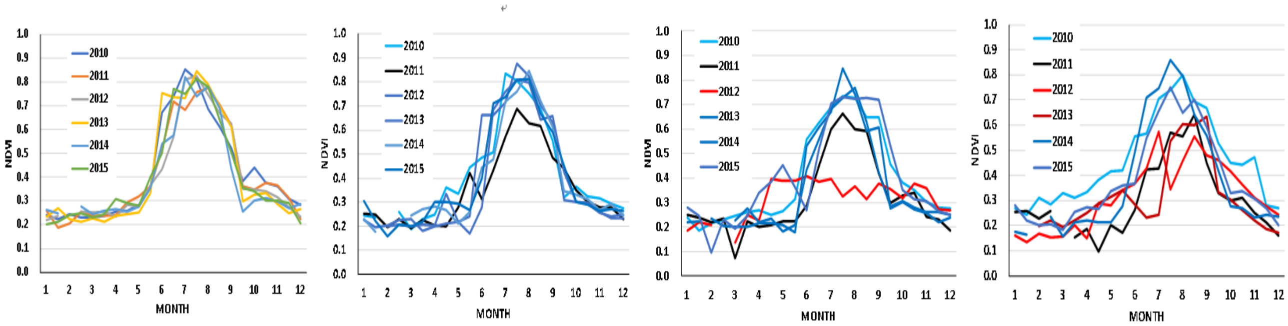


Figure 20. The agricultural recovery map of Sendai Area prepared by the Government of Miyagi Prefectural.

Figure 21(a) shows the NDVI seasonal variabilities of normal paddy fields 2010 to 2015. Since these paddy fields were not inundated by the tsunami, the seasonal variability pattern of each year is almost the same. Figure 21(b) shows the NDVI seasonal variabilities of inundated inland paddy fields from 2010 to 2015. The light blue line on Figure 21(b) shows the NDVI variability pattern of the paddy fields of Area-A for the year 2010 (before the Tsunami). The pattern is almost the same with that of normal paddy field as shown on Figure 21(a). The black line on Figure 21(b) shows the NDVI variability pattern of the year 2011. Compared with the light blue line of 2010 which reflects the typical NDVI pattern of normal paddy fields, the black line of 2011 shows the clear reduction of NDVI reflecting the damage of Tsunami on March 11. However, the NDVI variability pattern of 2012 shown on Figure 21(b) reflects that the paddy fields of Area-A recovered within one year after the Tsunami. Figure 21(c) shows the NDVI seasonal variability pattern of the paddy fields of Area-B from 2010 to 2015. Area-B is located more near to the seashore. The reduction of NDVI pattern from 2010 to 2011 is similar to Area-A. However, the NDVI pattern of 2012 was also low in Area-B. The NDVI of the following years indicate that the paddy fields of Area-B recovered in 2013 which means it took two years for the recovery. Figure 21(d) shows the NDVI seasonal variability pattern of the paddy fields of Area-C from 2010 to 2015. Area-C is located just next to the seashore. The reduction of NDVI after the Tsunami continued until 2013 and recovered in 2014. This means that it took three years for the recovery. As a result, the comparison of NDVI seasonal variabilities was quite effective for monitoring the paddy field recovery from the tsunami damages.

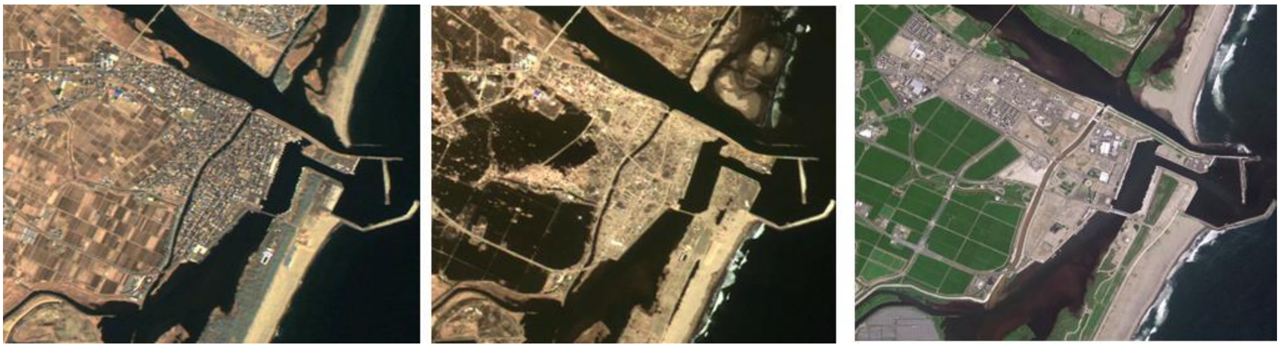


(a) **Normal paddy fields** **(b) Inundated inland paddy fields in Area-A** **(c) Inundated inland paddy fields in Area-B** **(d) Inundated inland paddy fields in Area-C**

Figure 21. NDVI seasonal variabilities of different types of paddy fields

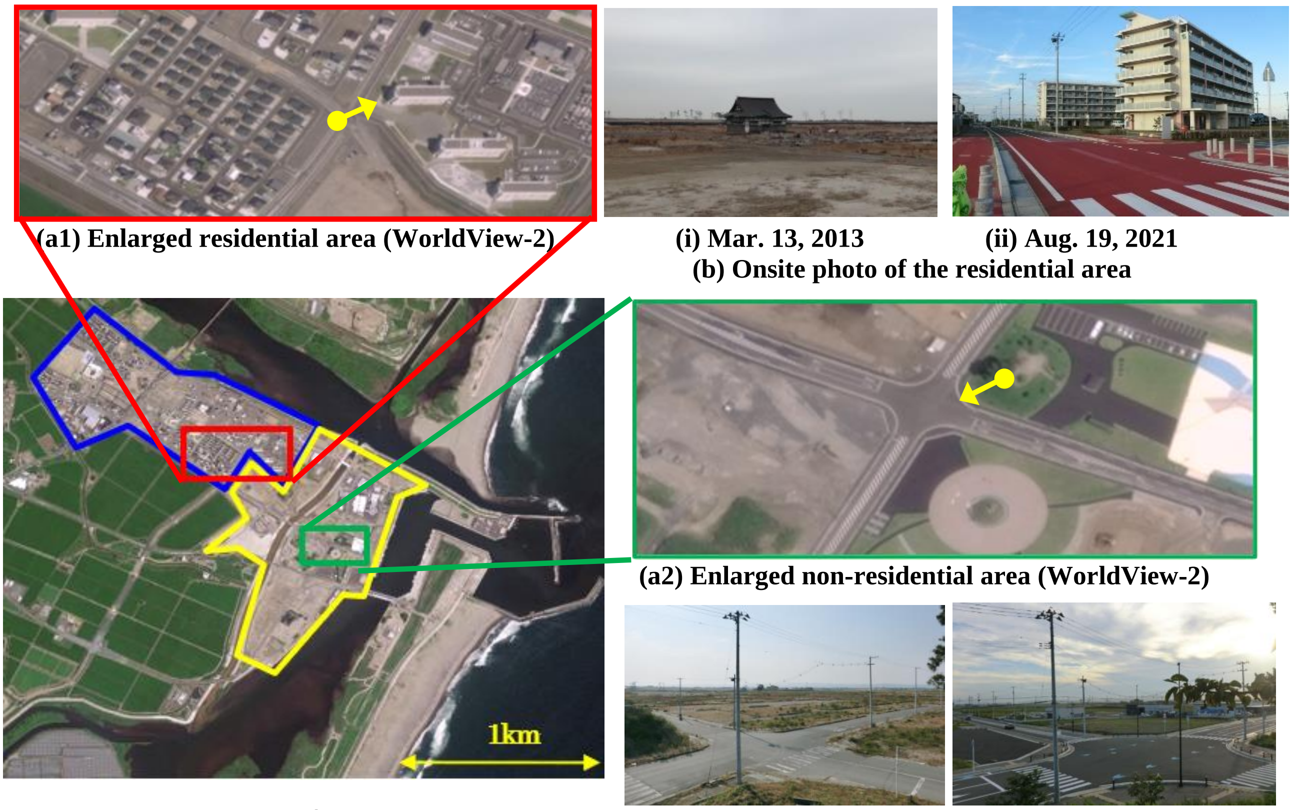
3.4 DIVELOPMENT OF EDUCATIONAL MATERIALS

After collecting time series of onsite photos and satellite images etc., the authors have benn developing educational materials for environmental recovery education. Figure 22 shows the satellite images of Yuriage Area of Natori City taken on March 11, 2011(just before the earthquake), March 19, 2011 and August 20, 2020. The population of Yuriage was 7103 before the Earthquake. The area was heavily damaged by the tsunami as shown in Figure 22(b). Total of 845 people were lost or still missing by the tsunami. Figure 22(c) shows the current outlook of Yuriage. Figure 23 shows an example of educational materials for environmental recovery education produced by connecting satellite image with onsite photos. Figure 23(a) shows the WorldView-2 images of Yuriage. After the Japan Earthquake, many of the local government of Tohoku Area decided not to build houses near the seashore, and decided to build high breakwater along the coast. In Yuriage, the local government decided to make two areas as shown on Figure 23(a). The area surrounded by blue line was assigned as residential area, and the area surrounded by yellow line was assigned as non-residential area. Figure 23(a1) shows the enlarged WorldView-2 image of residential area. 5m heightening was performed to the residential area, and many new buildings were constructed. Onsite photos of the area, as shown in Figure 23(b), show a big change of the area between 2013 and 2021. On the other hand, Figure 23(a2) shows the enlarged WorldView-2 image of non-residential area. Parks were constructed, but no buildings. Onsite photos of the area, as shown in Figure 23(c), shows almost no change in the view of this area between 2012 and 2021.



(a) Mar.11, 2011(FORMOSAT-2) (b)Mar. 19, 2011(FORMOSAT-2) (c) Aug. 20, 2020 (WorldView-2)

Figure 22. Satellite images of Yuriage reflecting the damages and recovery of the area.



(a1) Enlarged residential area (WorldView-2)

(i) Mar. 13, 2013 (ii) Aug. 19, 2021

(b) Onsite photo of the residential area

(a2) Enlarged non-residential area (WorldView-2)

(a) WorldView-2 image of Uriage (Aug. 20, 2020)

(i) Oct. 15, 2012 (ii) Aug. 19, 2021

(c) Onsite photo of the nin-residential area

Figure 23. An example of educational materials for environmental recovery education.

3.5 INFORMATION DISSEMINATION ON ENVIRONMENTAL RECOVERY

The author has been presenting the outcome of this study at various conferences and seminars (Cho, 2016, 2017, 2018) The Sendai Technical High School organizes memorial seminar every year on March 11 to remember about the Japan Earthquake. It was our pleasure to be invited to the seminar and gave a talk on this project which was performed with the students of the high school. The authors are also providing the information on the environmental recovery on our homepage. The URL of the homepage is http://www.ds.u-tokai.ac.jp/cholab/space-eye/index.html.

4. CONCLUSION

The main aim of this project was to perform environmental education through monitoring the recovery of damages areas in Tohoku by comparing satellite images with field survey. In the beginning of the project, the authors were not sure how we could monitor the recovery of the damaged areas after such serious disaster. However, after 10 years, the authors are now quite confident that Tohoku is steadily recovering and the monitoring the recovery with satellite images connected with onsite photos are quite effective for the education of environmental recovery after disasters. In the end, the authors would like to emphasize that the environmental recovery of Tohoku Area is still not over. We believe that it is our duty to continue our study.

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