FLOODED AREAS EXTRACTION DUE TO THE 2011 THAILAND FLOOD USING RADARSAT-2 AND THAICHOTE IMAGERY DATA

Pisut Nakmuenwai[1*] and Fumio Yamazaki[2]
[1] Graduate Student, Graduate School of Engineering, Chiba University, Japan;
Senior Computer Scientist, GISTDA, Thailand, pisut@gistda.or.th
[2] Professor, Graduate School of Engineering, Chiba University, Japan,
yamazaki@tu.chiba-u.ac.jp

*Corresponding author: pisut@gistda.or.th

ABSTRACT

This paper examines an extraction method of widespread flooded areas occurred in the Chao Phraya River basin, central Thailand, in the rainy season of 2011. RADARSAT-2 imagery data have been mainly used to extract affected areas, while THAICHOTE imagery data have been used as optical supporting data for the Thai Government. In this study, the same data were used in a somewhat different method with more deeply in detail. ScanSAR Narrow-mode imagery with cross-polarization of RADARSAT-2 was introduced to improve the accuracy and get more information on the ground surface. The SAR intensity images, which can be acquired also in the nighttime or under bad weather conditions, were found to be the most effective because the smoothness of water surface always shows low backscatter values. In the same way, the NDVI values calculated from the THAICHOTE images could also recognize flooded areas form open space under a clear sky condition. However, both of these sensors could not discriminate flooded urban areas easily because of the limitation of their spatial resolutions. Backscatter values still kept high although buildings were surrounded by water. The extracted results were validated by a high-resolution optical satellite image, water height data from gaging stations and a digital surface model (DEM) from LiDAR.

Keywords: 2011 Central Thailand flood, RADARSAT-2, THAICHOTE, Optical sensor, SAR

INTRODUCTION

Thai people have been living in flood-prone areas since an ancient time because they can move and transport goods though rivers, take advantage of fertile irrigated soil for farming, and prevent enemies during flood seasons. When the time has passed by, Thailand has achieved dramatic economic growth especially in the last decades. As the results of that, urban and industrial areas have been expanded to the flood-prone areas. Floods happening almost every year have brought dissatisfied situations. Severe flooding occurred during the 2011 monsoon season in Thailand. It spread throughout northern, northeastern and central provinces of the country. Sixty-five of Thailand's 77 provinces were declared as flood disaster zones. It caused heavy economic damage by disturbing industrial production activities and manufacturing supply chains of world's industries. The World Bank's estimated for this disaster that it ranked as the world's fifth costliest disaster as of 2011 [1], and its cost 1,425 billion baht (US$ 45.7 billion) in economic losses [2]. Thai Government highly concerned about its effects by taking actions to improve prevention solutions and to respond people with more accurate flood information [3].

In this study, satellite imagery data, the most effective ways for extracting information of large-scale disasters, are introduced. Because SAR sensors emit microwave without depending on sunlight conditions and microwave can penetrate cloud-cover, SAR can be used under all weather conditions in the daytime and nighttime to detect flooded areas. RADARSAT-2, a Canadian satellite operating in the C-band of the electromagnetic spectrum at a wavelength of 5.6 cm, had been mainly used for flood monitoring in Thailand since 2000 [4]. Unfortunately, COSMO-SkyMed, a constellation composed of four Italian satellites and acquiring data several times a day, had been introduced after the flooding has ended in 2012. To provide more complete information, the Thai first satellite, THAICHOTE, was used as optical supporting data when the sky was clear since 2004 [5, 6]. After the flood situation had ended in early 2012, a Digital Elevation Model (DEM) from LiDAR was brought into use for the first time in Thailand. The data would be very helpful to improve the accuracy of flooded areas extraction [3].

This study perform the extraction of flooded areas using RADARSAT-2 ScanSAR-mode images and the Normalized Difference Vegetation Indices (NDVIs) evaluated from THAICHOTE images. The results are examined by a high-resolution GeoEye-1 image, and then they are compared with water-height data from telemetering water gages and simulation results on the DEM.

STUDY AREA AND IMAGERY DATA

The Chao Phraya River basin covers 20,125 km^2 of 11 provinces in the north-south alignment. The water from upper stream is blocked by the mountains at the central Nakhon Sawan before passing through Ayutthaya, Bangkok and finally draining into the Gulf of Thailand [3, 4]. This region is not only the World Historical Heritage property (Ayutthaya) but also Thailand's Capital city (Bangkok), the hub for industries and trades with a number of industrial parks operated by Industrial Estate Authority of Thailand, as well as being the gateway to Indochina and south China [4]. This paper focuses on the central part of Ayutthaya, which includes Ayutthaya Historical Park, Rojana Industrial Estate and Hi-Tech Industrial Estate, about 16.5 km in width and 21.0 km in length (the GeoEye-1 area in **Figure.1**).

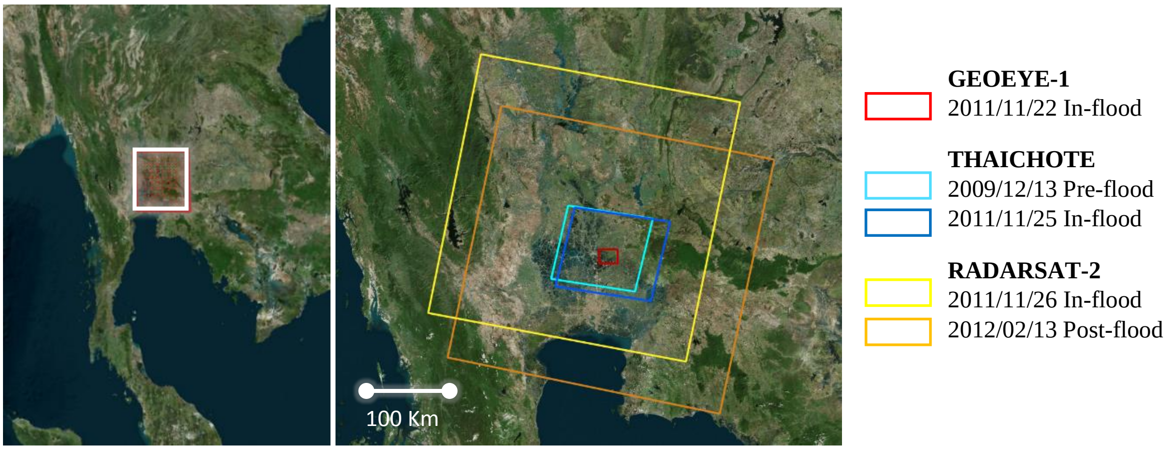


Figure 1. The Chao Phraya River basin and areas cover by satellite images used in this study

To detect floods in a large-scale area, ScanSAR mode data are usually used by Thai Government, even if several beam mode data acquired by RADARSAT-2 exist. Both ScanSAR Wide (SCW) mode with 50x50 m solution and ScanSAR Narrow (SCN) mode with 25x25 m solution can produce Single Co, Cross or Dual-polarization [7], but only HH (single) polarization is used in the most cases [4]. Although fully polarimetric data is the best for classification, that is not supported in the ScanSAR mode of RADARSAT-2. Therefore, in this study, SCN with HH and HV polarizations were employed for creating color composite images, which is much more helpful to identify objects on the ground [8]. An in-flood image observed on November 11, 2011 is in SCNA (W1+W2) beam types while a post-event image observed on February 23, 2012 is SCNB (W2+S5+S6) beam types. Both of them were observed from the descending path approximately in one minute, respectively at 6:07 and 6:12 in the local time of Thailand (UTC+7) as shown in **Figure 2**.

When the sky was clear enough, optical sensor satellites can be used to monitor the flooded areas. A GeoEye-1 image taken during the flood event on November 22, 2011 was used in this study. A pansharpened image of GeoEye-1, a 4 bands multispectral image with 1-m resolution, was a result of combination between a panchromatic image with 1-m resolution and a 4 bands multispectral image (B, G, R, NIR) with 4-m resolution. In the same way, a THAICHOTE multispectral image taken during the flood event on November 25, 2011 and another in the dry season before the flood on December 12, 2009 were used. Its sensor is similar to that of GeoEye-1 but resolution is lower (15 m), and pansharpening was not be processed (**Figure 3**).

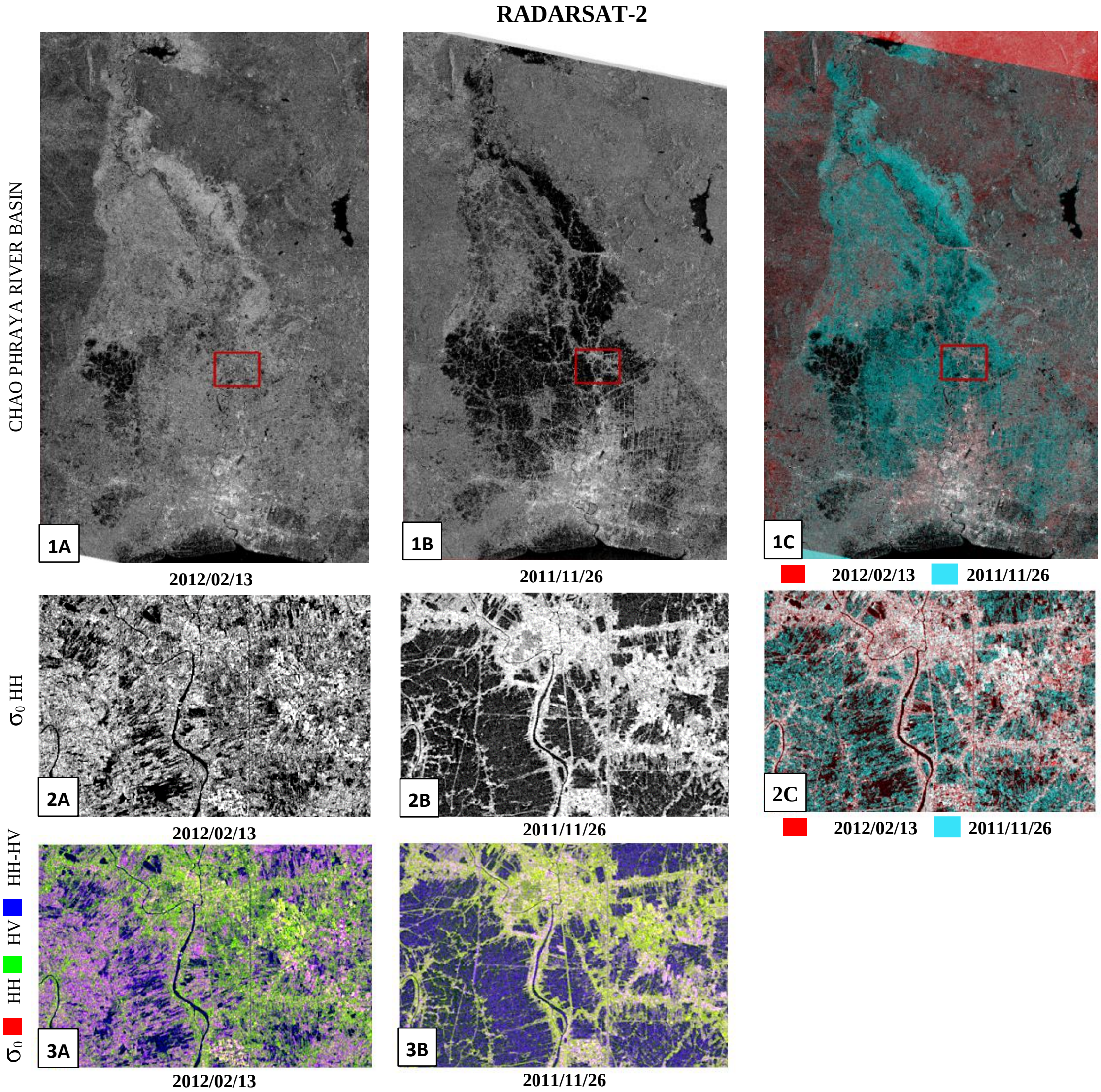


Figure 2. Comparison of backscattering coefficient (σ_0) HH from RADARSAT-2 for the post-flood and in-flood times in Chao Phraya River basin and for the study area (1A-2C) and dual polarization composite (HH+HV) for the study area (3A, 3B).

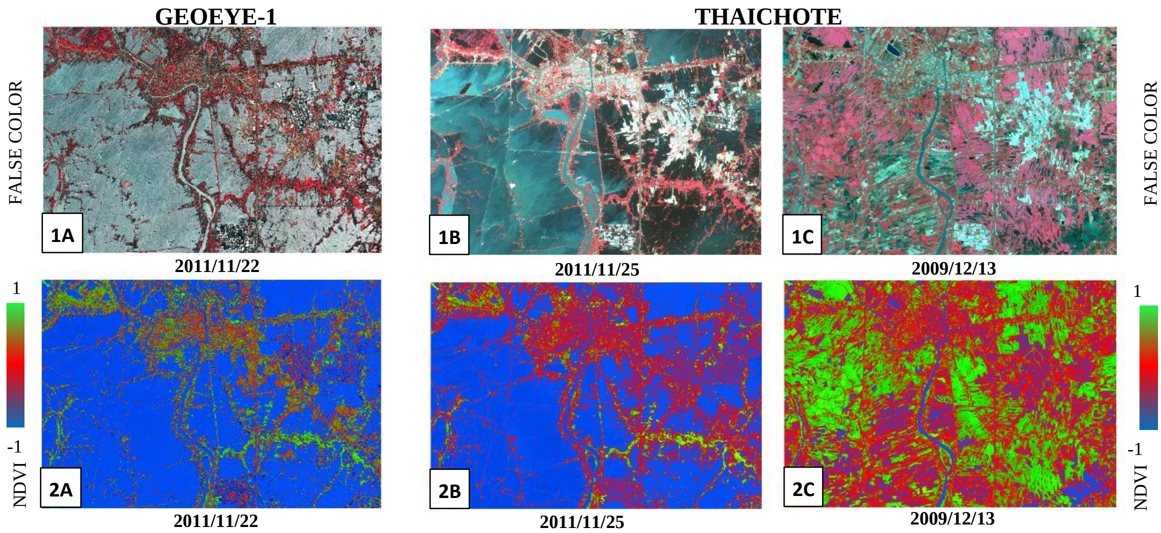


Figure 3. False color composites and NDVI values from GeoEye-1 for the in-flood time (1A, 2A) and from THAICHOTE for the in-flood and pre-flood times for the study area (1B-2C).

EXTRACTION OF FLOODED AREAS FROM GEOEYE-1 IMAGE

In this interpretation, rivers and ponds were also extracted as flooded areas because nearly the whole study area had been covered by water. In order to extract flooded areas from the GeoEye-1 image, the Normalize Different Vegetation Index (NDVI) was calculated from the Near-Infrared (NIR) and Red (R) bands [9, 10].

$$NDVI = (NIR-R) / (NIR+R) \quad (1)$$

Water bodies have low reflectance in the R and NIR spectral bands, and thus it leads to very low positive or even slightly negative NDVI values and water can be classified easily [11, 12] (**Figure 2** 2A). The threshold of NDVI for water body during the flood period was determined by visual interpretation as NDVI ≤ -0.11 or 73.8% of the image area (**Figure 4**).

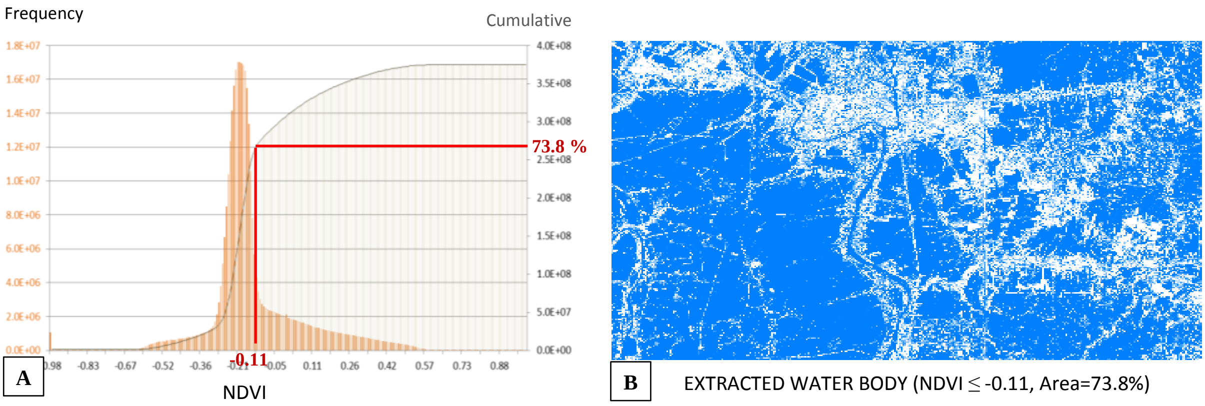


Figure 4. Histogram and cumulative probability plot of NDVI (A) and the extracted water areas (B) by the threshold (NDVI ≤ -0.11) from the in-flood GeoEye-1 image

EXTRACTION OF FLOODED AREAS FROM THAICHOTE AND RADARSAT-2 IMAGES

RADARSAT-2 and THAICHOTE are the main satellites to be used by the Thai Government in case of flood disasters. Normally, the threshold values of backscattering coefficient and NDVI have been used to extract flooded areas, comparing visually with optical images. In this study, those threshold values were determined from the NDVI from the GeoEye-1 image in the previous step.

The comparison between two (the truth data and the estimation) two-class spatial images, water body areas (W) or non-water body areas (N), results in 4 combinations: W-W, N-N, W-N, and N-W. When the threshold for a client image is set up to the minimum value, all of its results will be non-water body areas (N). Some of them are N-N, which represents the same N values as those from the master image (GeoEye-1), while the others are W-N which represents underestimated areas, the omission in water body extraction. When the threshold moves to higher values, some of the client image will be extracted as water body areas (W). Some of them are W-W which represents the same W values, while the others are N-W which represents overestimated areas, the exaggeration in water body extraction. The best threshold value is the point that the sum of W-W and N-N areas become largest. At this point, the most similar result with that from the GeoEye-1 image can be obtained.

Similar as GeoEye-1, THAICHOTE has an optical sensor with 4 bands and each band has the quite similar spectral range, but its spatial resolution is much lower. Before calculating NDVI values, THAICHOTE images were registered to the GeoEye-1 image. Then we compared their NDVIs with those from the GeoEye-1 image. It can be seen that the best NDVI threshold for water was -0.20, which corresponds to estimated water body of 73.1% (W-W and N-W) (**Figure 5** 2A and **Figure 6** 1A). Among these extracted areas, 83.24% were similar to those from the GeoEye-1 (W-W and N-N), 8.33% were omission (W-N) and 8.43% were exaggeration (N-W) (**Figure 5** 1A). By applying this NDVI threshold to the THAICHOTE's pre-flood image, the water-covered ratio for this area was 14.53% (**Figure 6** 2A).

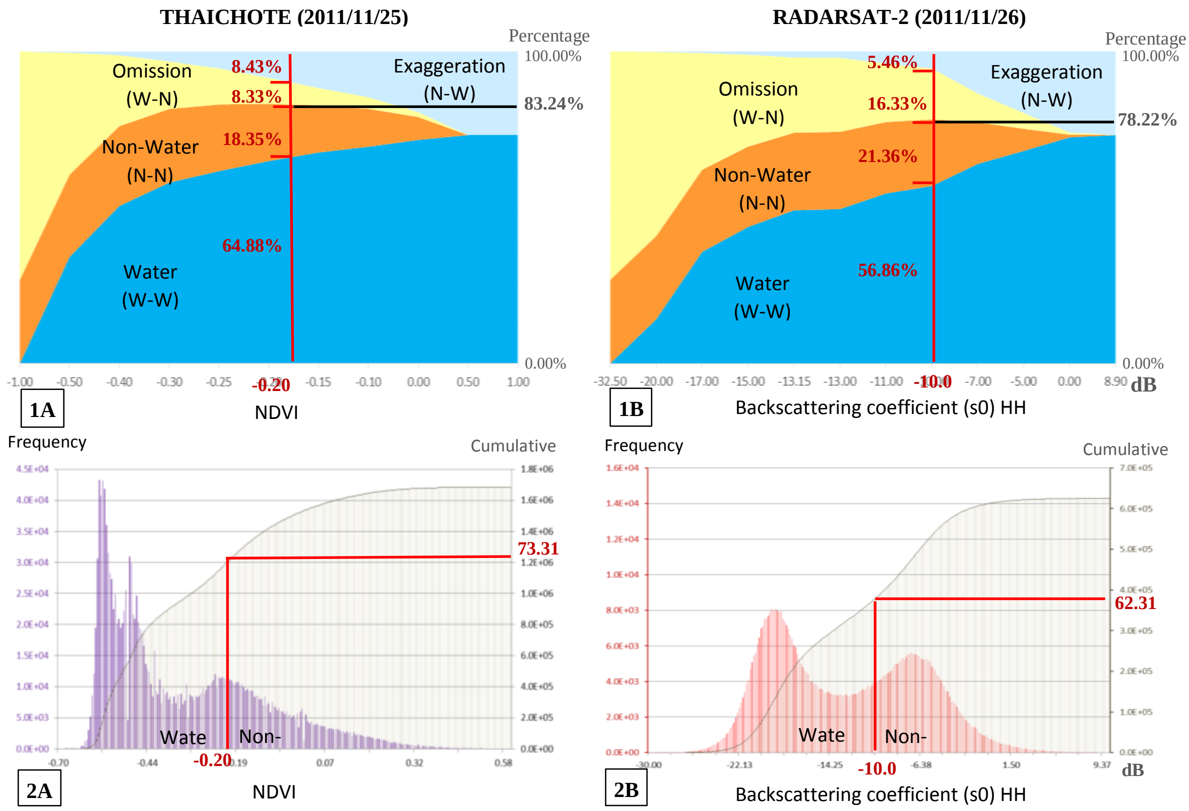


Figure 5. Relationship between the NDVI and σ_0 thresholds and extraction accuracy of water body (1A, 1B), and histogram and cumulative probability plot for NDVI (2A) and σ_0 (2B).

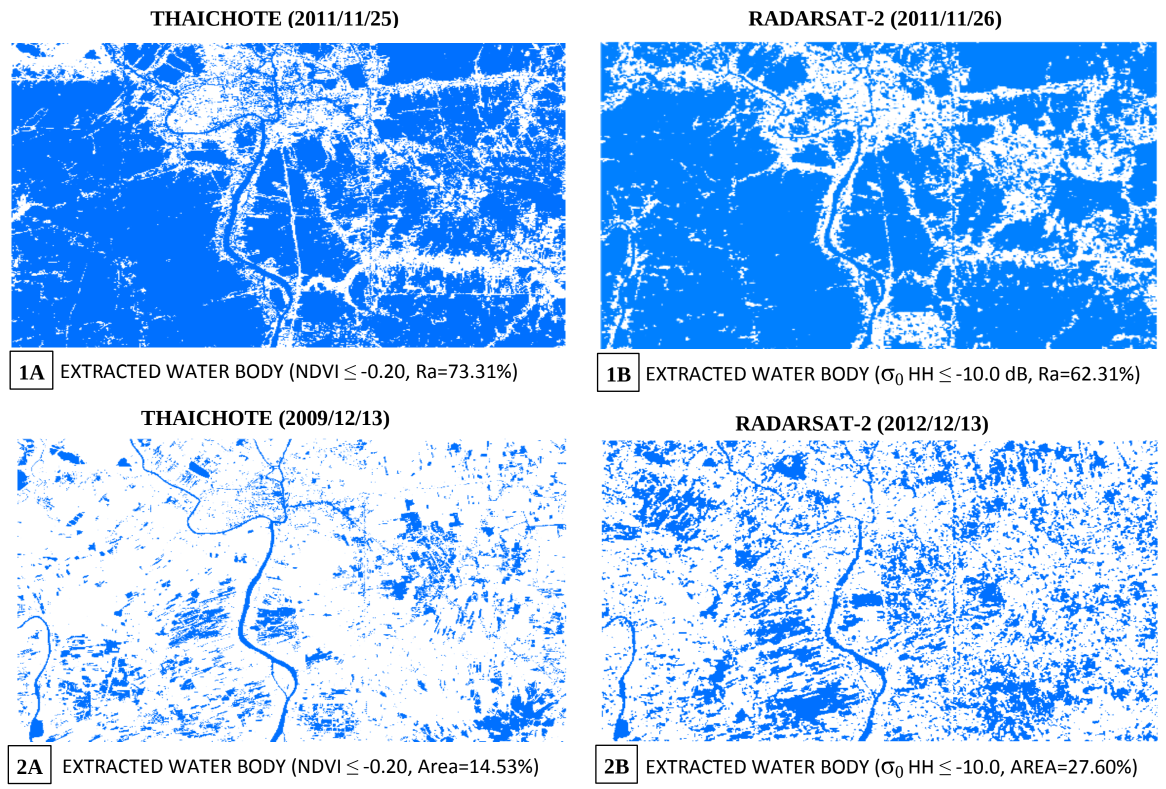


Figure 6. Extracted flooded areas (1A, 1B) during the flood from THAICHOTE and RADARSAT-2. Extracted water areas before the flood (2A) from THAICHOTE and after the flood (2B) from RADARSAT-2.

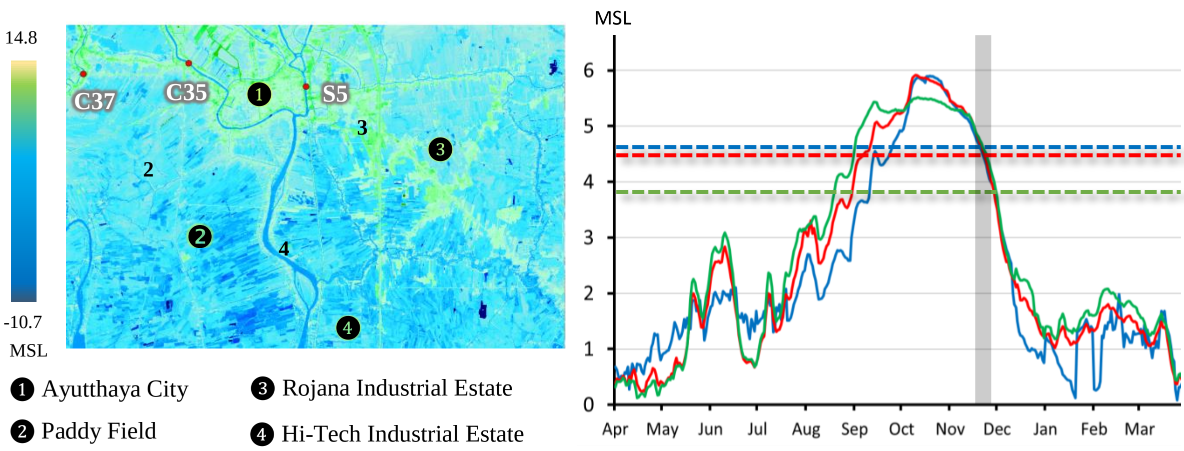
Although RADARSAT-2 has a different sensor from GeoEye-1 and THAICHOTE, the most standard image processing method to extract water body is the same technique, thresholding. The backscattering coefficient or Sigma Naught value (σ_0) is usually used instead of NDVI for optical sensors. The smoothness of water surface usually represents a low σ_0 value [4]. Before using RADARSAT-2 products acquired in the ScanSAR Narrow mode, they were processed in three steps. Firstly, calibration, an essential process for the quantitative use of SAR data, was applied to the images. The processed results can be directly related to the radar backscatter of the scene. Then, orthorectification was applied to derive the precise geolocation information by using the radar timing annotations, the slant to ground range conversion parameters together with the SRTM DEM 30 s reference. Finally, the Lee filter with 3x3 window size was used to the images for reducing speckle noise.

After the image had been processed, it was compared to the result from GeoEye-1. The best threshold of σ_0 HH can be obtained at -10.0 dB, which corresponded to the estimated water body 62.31% (W-W and N-W) (**Figure 5** 2B and **Figure 6** 1B). Among these extracted water body areas, 78.22% were similar to the results of GeoEye-1 (W-W and N-N), 16.33% were omission (W-N) and 5.46% were exaggeration (N-W) (**Figure 5** 1B). By using this σ_0 HH threshold to the RADARSAT-2 pre-flood image, the water-covered ratio for this area was 27.60% (**Figure 6** 2B).

WATER HEIGHT

Because the satellite images were not taken from the same sensors and cannot be acquired on the same date when the water height is assumed to be equal, it is difficult to explain the reason why evaluated water areas were different. Not only the difference of sensor type and spatial-resolution, but also the change of the water height may reflect the fact that the evaluated water areas from THAICHOTE and RADARSAT-2 are smaller than that from GeoEye-1. The area of land inundated and the height of flood-water were difficult to project because water flows down without stopping although rather slowly in this area. To understand the flood situation, the daily average water height above the mean sea level (MSL), collected from 3 nearest telemetry gaging stations (C35, C37 and S5) were be considered as truth data [13] (**Figure 7**).

The line graph demonstrates the water height at the 3 telemetry gaging stations located in the study area over one year period from April, 2011 to Mar, 2012. The period that the satellite images were acquired, it was the end of the flood situation which water level dramatically decreased. Although the water was slightly different in height on November 22, 2011, they significantly dropped more than 30 cm in 3 days on November 25, 2011, and nearly 10 cm in 1 day on November 26, 2011.



Station	Levee (MSL)
S5	4.70
C35	4.58
C37	3.80

Satellite Images	Acquired Date	Water Height (MSL)			Water Depth (Meter)		
		S5	C35	C37	S5	C35	C37
GeoEype-1	22/11/2011	4.48	4.56	4.62	-0.22	-0.02	0.82
THAICHOTE	25/11/2011	4.17	4.25	4.41	-0.53	-0.33	0.61
RADARSAT-2	26/11/2011	4.05	4.15	4.32	-0.65	-0.43	0.52

Figure 7. LiDAR DEM and telemetry gaging stations with their levee and water height above the MSL in the study area.

Since Ayutthaya is situated on a plane area, a little height of water may spread in a wide area. At that time, just only water height at station C37 was higher than the levee, which regulates water levels, resulted that the water at this station spread outside the river. Although the water heights of the others stations (S5 and C35) were under the levee and there was no water spread outside, the water was still remained on the ground and kept running to lower parts in the south. This fact might cause the extracted areas in this study were a little bit different from the gage data.

CONCLUTIONS

THAICHOTE and RADARSAT-2 images were used to extract water body due to the 2011 Chao Phraya River basin flood in the central Thailand. Those images could extract flood-affected areas easily by introducing thresholds to the NDVI value and backscattering coefficient. The extraction results, including water areas and dry areas, were very similar to the visual inspection result from an in-flood GeoEye-1 image around 80%. However, both of them could not detect flooded urban areas easily due to the limitation of their spatial resolutions. The results from the THAICHOTE image had more similarity for water body extraction because the NDVI value for water kept low even buildings were surrounded by water or not. On the other hand, the results form RADARSAT-2 underestimated flooded areas because the backscattering coefficient increased if buildings were surrounded by water. Another reason why the extracted water areas were less than that from GeoEye-1 was due to the change in the water height in time, decreasing at the end of the flood situation in November 2011. It was very hard to know the exact water heights for all areas because water was moving down to the south and sometimes was blocked by barriers.

ACKNOWLEDGMENT

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