Flood monitoring and damage assessment in Thailand using multi-temporal HJ-1A/1B and MODIS images

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Abstract. Flood is one of the most serious natural disasters in South Asia. How to monitor floods and assess damage caused is the most urgent problem for the government and disaster experts. With the advances of remote sensing, images acquired before the beginning of disaster to the very end or after the disaster from Earth-observing satellites benefit the decision making for reduction and protection of disaster dramatically. By using multi-temporal HJ-1A/1B and MODIS remote sensing data, applicability of different algorithms for flood monitoring and damage assessing was investigated in 2011 Thailand floods. Three different algorithms were adopted to monitor flood disaster events with water indices. Comparisons on the flood disaster monitoring and damage assessing by means of HJ-1A/1B and MODIS images suggested that multi-temporal HJ-1A/1B is much useful for the purpose, which demonstrated with the analysis of the thresholds estimated and problems in data post-processing. The variations of the inundated areas in the process of 2011 Thailand floods revealed were presented in this paper, and the damage caused by flooding was evaluated in three aspects, the population in the inundated region, the inundated information of different provinces and land use areas. Compared with MODIS, HJ-1A/1B images can provide more rapid and accurate flood extent and damage assessment for the disaster prevention, damage mitigation and disaster relief.

1. Introduction
Floods are the most damaging of all natural hazards, and, each year, result in major disaster response activities (such as food assistance provided by the World Food Programme). As one of the most frequent and severe natural disasters, floods cause huge human sufferings and property loss, and affect a wide range of activities related to agriculture, vegetation, human and local economics [1-3]. Climate and land cover directly affect flood and drought frequency and severity. Future changes in the Earth’s water cycle will have major impacts on the growing global population, and they cannot be accurately predicted without adequate knowledge concerning present conditions and rate of change since this work requires near real time information. However, the mapped record of flooding can improve future flood risk assessment, and it can be used in tandem with hydrological modelling to facilitate weather-based flow and inundation prediction. The rapid monitoring and damage assessment of floods, as the basis of the disaster prevention, damage mitigation and disaster relief, as well as an important component of Earth's water circle, therefore, have been one of the research hotspots and a huge

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challenge for the government and disaster experts [4].
In the last century, data analysis by the network of meteorological stations and hydrological observatories was widely used to predict and monitor floods [5]. With the development of remote sensing technique, various images from earth-observing satellites make it possible to obtain the ground information rapidly by means of sensors operating in several spectral bands such as SPOT, AVHRR, MODIS, HJ-1A/1B, RADARSAT, Envisat ASAR, which can provide the effective means to detect and assess disasters accurately [6-7]. Meanwhile, many flood monitoring algorithms by using different remote sensing data have been developed. Except common density slicing or image segmentation methods such as maximum likelihood method [8], with the spectrum information of water body, water body extraction techniques, such as spectrum-photometric method, water index algorithms, are widely used in flood related studies [9-12].
During August to December of 2011, a large-scale flood took place over the central Thailand, and this event was reported as the maximum recorded flood in recent 50 years of Thailand. During this flood, extensive areas of Thailand were inundated, about 7 industrial estates and 804 companies suffered inundation damage, which resulted in 813 dead and nearly 1.36 trillion baht loss nationwide [13-15]. By means of multi-temporal HJ-1A/1B and MODIS images acquired during this great flood, this study was aimed to map the flooded area from July 2011 to February 2012 for understanding the dynamic processes of 2011 Thailand flood, and meanwhile assessing the flood damage from multiple perspectives. The suitability of different water index methods by using different sensors were presented and compared with each other to investigate the function and limitation of water index methods on HJ-1A/1B and MODIS images in flood monitoring and assessments.

2. Study region
Located in the central part of Thailand, the Chao Phraya River basin has suffered several large-scale floods in history, and was one of the mostly inundated areas during 2011 Thailand flood. As shown in figure 1, the down-stream areas of the Chao Phraya River basin covers the provinces with huge damages in the flood, such as Bangkok and Ayutthaya, where the flooding dynamics of which can reflect the general condition of 2011 Thailand flood.

Figure 1. Study region.
3. Datasets and methods

3.1. Datasets

The HJ-1 mini-satellite constellation is a national program by the National Committee for Disaster Reduction and State Environmental Protection Administration (NDRCC/SEPA) of China, to construct a network of Earth observing satellites. HJ-1A/1B satellites include two 30m-resolution CCD optical cameras which work together to form a 700 km wide swath with a 4-day repeat cycle. Each CCD camera has three visible bands (430-520 nm, 520-600 nm, and 630-690 nm) and a near-infrared band (760-900 nm). In comparison, MODIS on board the Terra and Aqua satellites, has a viewing swath width of 2330 km, views the entire surface of the Earth every one to two days, and acquires data in 36 spectral bands between 0.405 and 14.385 µm, at three spatial resolutions -- 250m, 500m, and 1000m. Both HJ-1A/1B and MODIS data are widely used in flood monitoring. In this study, a time-series HJ-1A/1B and MODIS data set spanning from July 2011 to February 2012 were used. All the satellite images were calibrated and geometrically corrected using ENVI and MRT software.

Except the satellites images, to assess the damage of this flood, land cover map, population density data and administrative areas data are needed to provide the basis information of Thailand. A land use map of Thailand from GlobCover datasets in 2009 at the spatial resolution of 300m, administrative areas data from GADM datasets updated in 2015, and population density data in 2011 at the spatial resolution of 100 m estimated by WorldPop were chosen for the assessment.

3.2. Methods

3.2.1. Water body identification. Water body identification is the primary part of flood monitoring, mostly based on the spectral absorption characteristics of water body which differ very much from the other ground objects in visible and infrared bands [16]. In recent years, several water indices were developed by combining two or more bands for inundated area identifications, among which the normalized difference water index (NDWI) [9] is a popularized one in flooding monitoring and assessment for visible and infrared bands data applications. In this paper, inundated extent were derived from MODIS images by NDWI, the modified normalized difference water index (MNDWI), spectrum-photometric water index (SPWI) algorithms, and from HJ-1A/1B images only by NDWI methodology.

According to Mcfeeters (1996), the normalized difference water index that can enhance the water information by the difference of water spectral absorption intensity in green and near-infrared bands can be calculated as:

$$NDWI = \frac{(\text{Green} - \text{NIR})}{(\text{Green} + \text{NIR})}$$ \hspace{1cm} (1)

Where Green is the reflectance of green band and NIR is that of near-infrared band.

To improve the accuracy of water body extent identification from soil and buildings with NDWI, MNDWI was proposed by Xu (2005) based on a combination of reflectance in the green and mid-infrared wavelengths. The MNDWI can be calculated as:

$$MNDWI = \frac{(\text{Green} - \text{MIR})}{(\text{Green} + \text{MIR})}$$ \hspace{1cm} (2)

Where MIR is the reflectance of mid-infrared band.

A water spectral model was established by Ding et al. (2006) for extracting water body by using MODIS images, as regard to spectrum-photometric method. This model can be expressed as:

$$CH_1 + CH_4 > CH_2 + CH_6$$ \hspace{1cm} (3)

Where $CH_1$, $CH_2$, $CH_4$, $CH_6$ is the reflectance of band 1, 2, 4, 6 in MODIS images, respectively. According to the model, SPWI can be calculated as:

$$SPWI = CH_1 + CH_4 - CH_2 - CH_6$$ \hspace{1cm} (4)
A suitable cut-off threshold was needed to extract water body by using these three water indices. The pixel values of NDWI, MNDWI, SPWI images derived from satellites images range from −1 to 1. In general, pixels with the three indices value greater than 0 represent water bodies. But due to the different water index values of the same location from various images, slight calibration of the thresholds is necessary for more accurate results [17]. Therefore, the water indices values of several sample points classified as inundated areas by the visual interpretation from HJ-1A/1B images were calculated to adjust the thresholds to distinguish water body from other objects. Tests showed that thresholds of images obtained at different time of year by the same sensor were similar. The thresholds of NDWI from HJ-1A/1B images were concentrated in 0.29, and NDWI, MNDWI, SPWI thresholds from MODIS images were concentrated in 0, 0.1, 0, respectively.

3.2.2. Data Post-processing. Compared with other water body extraction application, the monitoring of floods is more difficult because of the specific characteristics of flooded areas, which are always partly covered by water because the top of other objects may extent up to the water surface even during the flood. Thus, the value of pixels represented inundated areas is sometimes the mix of the reflectance of water and other objects, which may cause the misclassification especially by methods based on pixels. Therefore, open and close operators, the mathematical morphology methods, were used for noise removal in this paper, because open operator can remove small objects from the foreground of an image, placing them in the background, while close operator removes small holes in the foreground, changing small islands of background into foreground. Compared with results from MODIS images, the HJ-1A/1B monitoring results need more times of open and close operators performed, which reduces the degree of detection automation.

4. Results and discussions

Monitoring results showing the comparisons of monitoring data derived from MODIS and HJ-1A/1B images (table 1) are presented below.

| Method             | Oct.2011 | Nov.2011 | Dec.2011 |
|--------------------|----------|----------|----------|
|                    | Inundated Area (km²) | Overall accuracy (%) | Inundated Area (km²) | Overall accuracy (%) | Inundated Area (km²) | Overall accuracy (%) |
| Visual Interpretation | 10879.15 | /         | 9365.68 | /         | 8420.66 | /         |
| MODIS-NDWI          | 8023.25  | 73.75%    | 10132.97 | 91.81%   | 10887.25 | 70.71%   |
| MODIS-MNDWI         | 12639.75 | 83.82%    | 9858.00 | 94.74%   | 6868.00  | 81.56%   |
| MODIS-SPWI          | 9433.50  | 86.71%    | 7819.25 | 83.49%   | 5925.50  | 70.37%   |
| HJ-1A/1B-NDWI       | 9688.64  | 89.06%    | 8797.10 | 93.93%   | 7780.57  | 92.40%   |

In this paper, the visual interpretation results were regarded as “ground truth” to evaluate the accuracy of monitoring and identify the errors in the estimation. As shown in table 1, it is almost certain that HJ-1A/1B monitoring results are superior to others in this study, the mean accuracy of which is 91.80%, higher than that of MODIS results, 81.88%. Besides, the results derived from MODIS data using different methods are also distinct greatly, where MNDWI method is tested best.

The accuracy difference between HJ-1A/1B and MODIS images can be explained by the spatial resolution. Though MODIS images have more spectral bands and shorter repeat cycle, the lower spatial resolution causes the edge of flooded area and the mixed pixels harder to be defined due to the more complex mix of reflectance of various objects. And with more ground area corresponding to one pixel, the misclassification will lead to more area errors. It can also explain the variation among the results from different methods on MODIS images, which are not stable because many factors such as the thresholds estimated, the classification of mixed pixel, differs among the three methods. Therefore, the detail of monitoring process on MODIS images should be more concerned, because of the error
caused by slight adjustment which cannot be ignored, though the estimation of thresholds and data post-processing for MODIS images are simpler and need fewer tests.

**Figure 2.** Maps of inundated areas derived from HJ-1A/1B images from Sep 2011 to Feb 2012. (a) Sep 2011; (b) Oct 2011; (c) Nov 2011; (d) Dec 2011; (e) Jan 2012; (f) Feb 2012.

**Figure 3.** The Changes of inundated area and the population of inundated region from Sep 2011 to Feb 2012.
Figure 2 gives the inundated extent achieved from HJ-1A/1B images from September 2011 to February 2012, with the extraction result in July 2011 representing the normal water body extent before floods. The change of inundated area demonstrates the process of 2011 Thailand flood, which occurred in central and southern Thailand in Aug 2011 [15], quickly spread to the surrounding, especially in Phra Nakhon Si Ayutthaya Province, peaked in October and November 2011, and receded till February 2012. The inundated area and the population of inundated region are shown in figure 3, the changes of which are also consistent with the process of this flood analyzed above.

### Table 2. Inundation area in different provinces.

| NAME                        | Area (km²) |
|-----------------------------|------------|
|                             | Sep-11     | Oct-11 | Nov-11 | Dec-11 |
| Phra Nakhon Si Ayutthaya    | 322.73     | 1919.41| 1750.48| 1776.17|
| Suphan Buri                 | 160.87     | 1056.37| 904.92 | 1064.93|
| Lop Buri                    | 134.49     | 589.42 | 470.12 | 426.73 |
| Pathum Thani                | 0.00       | 534.88 | 689.78 | 473.61 |
| Ang Thong                   | 11.27      | 431.12 | 350.25 | 387.55 |
| Nakon Pathom                | 0.00       | 384.79 | 476.46 | 818.10 |
| Sing Buri                   | 130.24     | 374.03 | 260.85 | 212.82 |
| Chai Nat                    | 79.43      | 343.70 | 214.57 | 75.86  |
| Saraburi                    | 42.39      | 202.75 | 172.85 | 141.36 |
| Nonthaburi                  | 0.17       | 188.15 | 197.20 | 256.44 |
| Nakon Nayok                 | 246.98     | 128.02 | 223.53 | 16.90  |
| Bangkok Metropolis          | 20.40      | 41.39  | 260.56 | 155.27 |

### Table 3. Inundation area of different land use types.

| Land Cover                                | Area (km²) |
|-------------------------------------------|------------|
|                                           | Oct-11     | Nov-11 | Dec-11 |
| Post-flooding or irrigated croplands      | 5134.25    | 4753.52| 3861.16|
| Mosaic cropland/vegetation                | 1834.56    | 1540.72| 1321.53|
| Rainfed croplands                         | 1529.48    | 1341.60| 1308.30|
| Closed to open shrubland                  | 243.08     | 150.58 | 45.49  |
| Closed to open herbaceous vegetation      | 165.31     | 167.87 | 258.50 |
| Open broadleaved deciduous forest/woodland| 132.25     | 135.18 | 111.14 |
| Closed to open broadleaved evergreen or semi-deciduous forest | 15.38 | 4.63 | 5.35 |
| Artificial surfaces and associated areas   | 13.23      | 37.83  | 63.57  |
| Closed needleleaved evergreen forest       | 10.89      | 11.83  | 19.88  |
| Closed to open mixed broadleaved and needleleaved forest | 9.58 | 22.42 | 41.57 |
| Bare areas                                | 6.18       | 4.55   | 4.09   |
| Closed broadleaved deciduous forest        | 5.55       | 4.59   | 4.57   |
| Mosaic forest or shrubland / grassland     | 2.28       | 6.60   | 8.21   |
| Permanent snow and ice                     | 0.32       | 0.32   | 0.32   |

Different regions and land use areas in Thailand were affected by 2011 flood to varying degrees. The statistics of flooded area of different land use types and provinces are shown in table 2 and table 3, indirectly reflecting the flood damage. As shown in table 2, a number of provinces which have
significant influence among Thailand's politics, culture, economy and modern society, suffered huge damage during this flood, including Bangkok Metropolis, the capital of Thailand. Among these, Phra Nakhon Si Ayutthaya province was affected most seriously in the study region, the inundated area of which peaking at 1919.410 km$^2$ in October 2011, accounting for 75.37 percent of the total area. Besides, it can be found that the croplands were the land use types damaged most severely from table 3, corresponding to the report by Thai Ministry of Interior, which caused huge reduction in yield [13].

5. Conclusions
Remote sensing technology is powerful for flood monitoring and damage assessing, which is capable of providing considerable inundation information in near real time. However, the different applicability of algorithms and kinds of images in flood monitoring still limit the accuracy of monitoring results. In this paper, the comparisons of monitoring data derived from MODIS and HJ-1A/1B images in 2011 Thailand flood were presented, which show that HJ-1A/1B images are more suitable for the flood monitoring by providing higher spatial resolution information. The results also demonstrated that MNDWI index can provide more accurate results compared with NDWI and SPWI indices. Depend on the monitoring information derived from multi-temporal HJ-1A/1B images, the damage of 2011 Thailand flood was analysed, showing that the flood peaked in October and November 2011, caused huge damage in several provinces and affected croplands severely, corresponding to the news and reports by Thai Ministry of Interior. The successful application of HJ-1A/1B images in flood monitoring and assessment demonstrated the potential of this satellite data in disaster prevention, damage mitigation and disaster relief applications, however, more researches about algorithms and data post-processing are need to improve the accuracy and automation of remote sensing monitoring.

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