NATIONWIDE FLOOD INUNDATION MAPPING IN BANGLADESH BY USING MODIFIED LAND SURFACE WATER INDEX

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ABSTRACT

Near-real-time flood flood mapping is one of the most important parts of emergency response efforts. This paper aims to estimate extreme flood inundation area over the entire Bangladesh, where monsoon river floods are dominant and frequent, affecting over 80% of the total population. The authors improved a water-extent extraction method for a better discrimination capacity to discern flood areas from cloud and mixed areas by using a modified land surface water index (MLSWI) based on the Moderate Resolution Imaging Spectrometer (MODIS) 8-day composites (approx. 500m resolution) data. Flood areas in the Brahmaputra River were verified by comparing them with ALOS AVNIR2 (approx. 10m resolution) data. The results showed the superiority of the developed method in providing instant and accurate nationwide mapping of floodwater extent in the three main rivers for the 2007 extreme event in the Bangladesh.

Keywords: Flood mapping, Modified LSWI, MODIS, ALOS

INTRODUCTION

An extreme monsoon river flood occurs approximately once every five to ten years in Bangladesh, and has a significantly negative impact on the country. Every year one-fourth to one-third of the national land is inundated during the monsoon season by overflowing rivers. The government of Bangladesh is seriously concerned to mitigate flood losses. Preparation of a flood hazard map for the monsoon season would be one of the most crucial steps for implementing non-structural remedial measures. Near-real-time flood mapping can be very useful by quickly providing effective water information to assist local and national management agencies in making informed decisions and optimizing their emergency responses. Flood detection is one of the classical themes of satellite-based remote sensing and now shifting towards developing technology for near-real-time flood inundation mapping in selected areas.

Since the launch of the Moderate Resolution Imaging Spectrometer (MODIS) in December 1999, it has become possible to monitor flood areas on a continental scale for 24 hours with a moderate-resolution optical sensor (spatial resolution 250–500 m). MODIS data collections are derived from both the Terra MODIS and Aqua MODIS instruments. One of the greatest benefits of MODIS sensors is that images with a wide swath range (2 330 km) can be distributed freely via the internet throughout the world (Pinherio et al, 2007). For instance, NASA and USGS (2007) have opened online flood maps for fundamental observational information with a rapid flood inundation mapping technique. These online data are available for downloading and also monitoring nationwide flood disasters all over the world with spatial and temporal changes. The Dartmouth Flood Observatory (2008) uses a water detection algorithm based on a reflectance ratio of MODIS band 1 and band 2 and a threshold on band 7 to provisionally identify pixels as water.

Many other water-body identification methods have also been developed. Thresholds for distinguishing between water and land pixels are based on the reflectance of the near-infrared channel. Remote sensing-based index algorithms designed to detect surface water are conceptually simple, relying mainly on spectral indices, such as Normalized Difference Vegetation Index (NDVI) (Rouse et al, 1973) and Land Surface Water Index (LSWI) (Xiao et al, 2008). Spectral indices with better detection capability are necessary to assess water status on land surface in a spectrally normalized way, such as MLSWI (Kwak et al, 2014a, 2014b), which was developed from LSWI with focus on flood event detection. Kwak (2014a; 2014b) evaluated and analyzed the performance of the MODIS-Aqua-derived floodwater products, considering the near-infrared (NIR, 841-875nm) and short waved infrared (SWIR, 1628-1652nm) reflectance coupled with simple index methods in the case of the 2010 Indus River flood over the entire Pakistan.

In this study, we focused on the sensitivity of water indices to floodwater detection in the entire Bangladesh, where monsoon river floods are dominant and frequent, affecting over 80% of the total population of the country. The authors improved a water-extent extraction method for a better discriminating capacity to discern flood areas from cloud and mixed areas by using the modified land surface water index (MLSWI) derived from the MODIS Aqua and Terra (approximately 500m resolution). Moreover, we evaluated and analysed the performance of floodwater products, considering the near-infrared (NIR, 0.84-0.87μm) and short waved infrared (SWIR, 1.62-1.65 μm and 2.13-2.22 μm) reflectance coupled with simple index methods. At the same time, flood areas were verified by comparing them with ALOS AVNIR2 (approximately 10m resolution) data. The satellite-derived product uncertainties in the Brahmaputra River were confirmed by using ground station data and field survey results.

STDUY AREA AND DATA USED

The study area was the entire Bangladesh, which is located at the downstream end of the floodplain delta formed by three major rivers, i.e., Ganges, Brahmaputra and Meghna (GBM), lying between Latitude 20–27 °N and Longitude 88–93 °E. Monsoon floods are mainly caused by a huge inflow from the upper GBM catchment due to intense rainfall during the monsoon period from June to October. Every year one-fourth to one-third of the country is inundated during the monsoon season due to overflowing rivers. Monsoon floods occur at many locations around the country except tidal and estuary flood plains, northern and eastern hills and the old Himalayan piedmont plain. Estuary and tidal flood plains are generally affected by floods due to storm surges and cyclones, but these are not frequent.

Following significant floods in 2004 and 2007 in Bangladesh, we selected multi-temporal MODIS images and high resolution images for inundation mapping with flood monitoring as listed in Table 1. First, two data sets were used in this study: Moderate-resolution Imaging Spectro-radiometer (MODIS) data obtained aboard Terra or Aqua platforms. The MODIS Aqua and Terra level-3 8-day composite surface reflectance products (MYD09A1 and MOD09A1) contain the best observation during an 8-day period as selected on the basis of high observation coverage, low view angle, the absence of clouds or cloud shadow, and aerosol loading at 500-meter (USGS LPDAAC, 2013). Second, to verify the floodwaters from MODIS images, we used 10-meter multi-spectral scanner (AVNIR-2) optical images, acquired on 23 December 2006 and 10 August 2007, of the Advanced Land Observing Satellite (ALOS), which was launched by the Japan Aerospace Exploration Agency (JAXA) in 2005. ALOS AVNIR2 images captured the Sirajgonj district under the same pre- and post-flood conditions. The district is 2,480 km^2 and located in the northern central region of Bangladesh near the levee of the Brahmaputra River.

Table 1. List of MODIS (NASA) and ALOS AVNIR2 (JAXA) images

Satellite	Optical sensor	Acquisition time (UTC)		Ground resolution
MODIS	Aqua (MYD09A1)	28 Jul - 4 Aug 2007 05 -12 Aug 2007	Post-flood	500 m (2440km×2440km)
		22 - 29 Mar 2007	Pre-flood	
	Terra (MOD09A1)	28 Jul - 4 Aug 2007 05 -12 Aug 2007	Post-flood	
		22 -29 Mar 2007	Pre-flood	
ALOS	AVNIR2	10 Aug 2007	Post-flood	10 m (7km×7km)
		23 Dec 2006	Pre-flood	

FLOOD IDENTIFICATION

The water identification steps for flood inundation mapping are as follows:

1. Check the spectral reflectances among the land-cover classifications
2. Compare the water indices (NDVI, LSWI, MLSWI)
3. Detect permanent water from pre-flood images with an optimal threshold
4. Mark as flood extend to the outside pixel of the permanent water from post-flood images
5. Generate a flood inundation maps comparing with high resolution images

According to these steps, Figure 1 shows the flow chart of flood inundation mapping

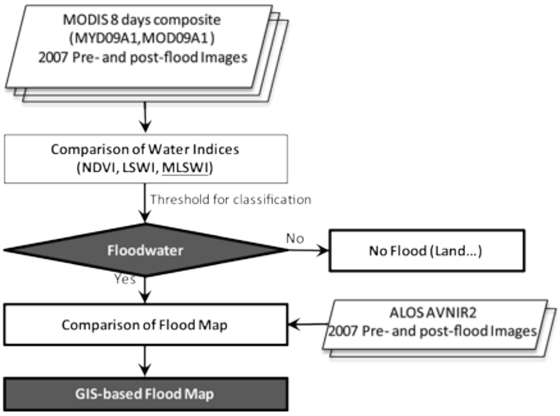

Figure 1. Flow chart of flood inundation map production

Comparison of Water Indices

This study focused on the use of MLSWI for flood mapping in a nationwide comprehensive approach. Figure 2 shows spectral reflectance from sample data in MODIS images for confirmation of flood-detection indices. In Figure 2a and 2b the characterization of land-cover classification and mixed water in flooding are illustrated. Permanent water needs to satisfy the following two conditions to be extracted as water body: band 1 +10% > band 2, (e.g., clean water < 0.1, as shown in Figure 2.a). The reflectance ratios of bands 6 and 7 are lower than those of bands in the case of permanent water such as clean, muddy and mixed waters, which reflect the temporal-spatial pattern of water content using supervised classification (Figure 2.b).

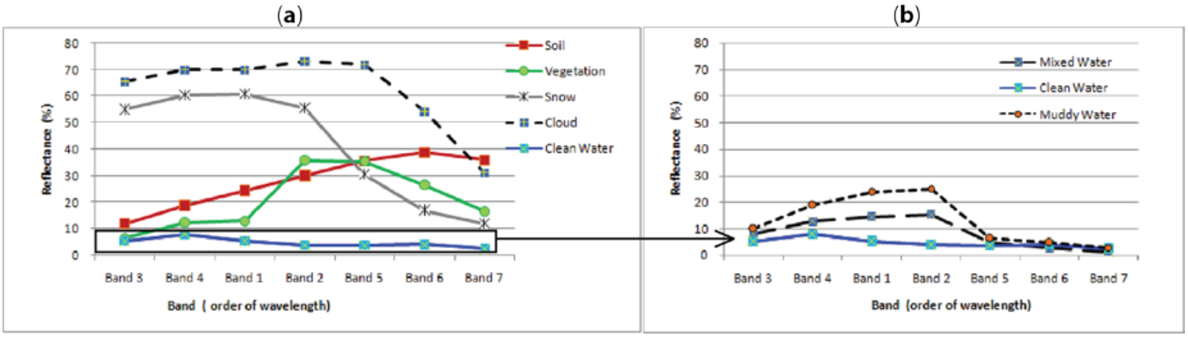

Figure 2. Spectral reflectance by land-cover classification (a) and the characteristic of mixed water in flooding (b)

In order to determine floodwater pixels more accurately, it was necessary to improve a surface-water extraction method for identifying flood areas from MLSWI in comparison with short waved infrared (SWIR band 6 and 7, 1.62-1.65 μm and 2.13-2.22 μm, respectively) reflectance, proposed as Equation 1:

$$MLSWI_{Flood} = \frac{1 - R_{NIR} - R_{SWIR}}{1 - R_{NIR} + R_{SWIR}}$$

Equation 1

MLSWI was then compared with NDVI and LSWI, the most frequently-used indices that have been proved effective in detecting soil moisture, vegetation and water-related objects. These indices were calculated as follows:

$$NDVI = \frac{R_{RED} - R_{NIR}}{R_{RED} + R_{NIR}}$$

Equation 2

$$LSWI = \frac{R_{NIR} - R_{SWIR}}{R_{NIR} + R_{SWIR}}$$

Equation 3

where R_{RED}, R_{NIR}, and R_{SWIR} are reflectance values (R) of MODIS bands 1, 2 and 6 or 7, respectively. An optimal threshold of each water index needs to be established to separate water bodies from other land-cover features based on the spectral characteristics.

Comparison of Flood Mapping

The actual flood event duration in 2007 was 15 days with a 10-year return period (BWBD, 2013). We used two sets of MODIS time series data to satisfy flood duration and efficient cloud reduction. First, MODIS captured the flood event between 28 July and 12 August 2007. Next, the permanent water was extracted from two images (MYD09A1 and MOD09A1) capturing the same area four months earlier between 22 and 29 March 2007. These images were each processed in four different patterns to compare the four water indices of NDVI, LSWI, MLSWI combining bands 2 and 6 (MLSWI2&6), and MLSWI combining bands 2 and 7 (MLSWI2&7). In a flooded area, the pixels were sorted out into three types: land-to-water (flood), water-to-water (permanent water), and land-to-land (permanent land). However, cloud cover and shadow diminished the ability to capture floodwaters in some areas, and thus cloud-affected pixels were omitted. We used gauging station data to validate satellite-derived river floods. The gauging station records contain overflow reaching very close to a dangerous level, i.e., over the maximum water level in the river. Geo-location information was also obtained from BWBD Flood Forecasting & Warning Centre (FFWC). Finally, the flood events were confirmed according to the flood detection in the Brahmaputra River from the high-resolution satellite data of the ALOS AVNIR2 images.

RESULTS AND DISCUSSION

This study confirmed the optimal value for the MLSWI threshold to be the most effective at 0.75 by using a heuristic approach to identify water bodies, such as permanent water, muddy water, and mixed water caused by flood. Permanent water bodies and floodwaters were separated based on a simple threshold from MLSWI variation. The critical value of the reflectance ratio was determined based on the spectral difference between water and land-cover types from training data. Figure 3 shows the results from applying the different water indices, i.e., NDVI (Figure 3.b), LSWI (Figure 3.f) and MLSWI combinations, i.e., MLSWI2&6 (Figure 3.c and Figure 3.g) and MLSWI2&7 (Figure 3.d and Figure 3.f), using MOD09A1 and MYD09A1 images. The Sirajgonj district was chosen to show the superiority of flood detection during the peak inundation. For example, NDVI (threshold: below -0.2) and LSWI (threshold: over 0.5) underestimated flooded land and floodwaters over mixed-water zones due to overflow from the Brahmaputra River. When comparing MOD09A1 and MYD09A1 images, we found that MLSWI2&6 and MLSWI2&7 had a very similar value ranging from -1.0 to 1.0 with small variation. These images presented the nearly same performance of the proposed method, except the ambiguity between cloud shadow and water pixels (the cloud condition relies on Terra and Aqua platforms). For example, MLSWI2&6 was 0.02 lower than MLSWI2&7 in mixed and flooded land pixels, suggesting that MLSWI2&7 is more slightly sensitive to those types of pixels to generate accurate flood maps in consideration of mixed areas.

We analyzed the 2007 flood event with a 10-year return period over the whole country of Bangladesh from July to August 2007. Figure 4 illustrates the inundation maps resulting from combination of Terra and Aqua MODIS images (Figure 4.a), comparison of the permanent water body before river flood (Figure 4.b), and comparison of the permanent water body after flood (Figure 4.c) with a high-resolution ALOS AVNIR images. The combination of Terra and Aqua MODIS showed 42% of the total country area was under inundation during 16 days in 2007. The inundation map in Figure 4.a was produced by MLSWI2&7 in which the red color presents the floodwaters during 5-12 August 2007 and the blue color represents the permanent water bodies captured before flooding between 22 and 29 March 2007. Although flood areas smaller than a resolution of 500 m were not detected accurately in the case of MODIS, the plotted permanent river water (Figure 4.b) from MODIS were nearly accordance with a high-resolution ALOS AVNIR images for the most vulnerable areas of the main stream (e.g., the Sirajgonj district). On the other hand, MODIS detected floodwaters over land irregularly as shown in Figure 4.c.

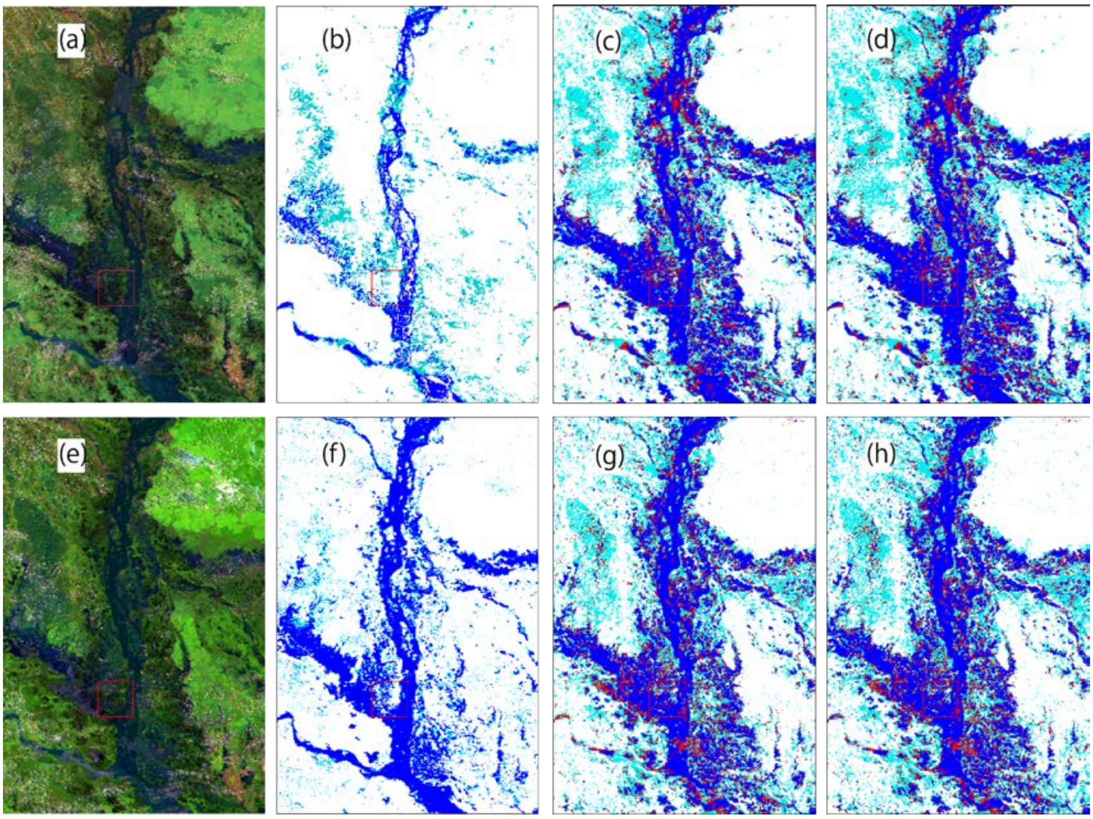

Figure 3. MODIS Terra (a) & Aqua (e) color composite surface reflectance image (red=band 7, green=band 2, blue=band 4) using 500-m data acquired between 5-12 August 2007, and six images with four different water indices of NDVI (b), LSWI (f), MLSWI2&6 (c, g), and MLSWI2&7 (d, h)

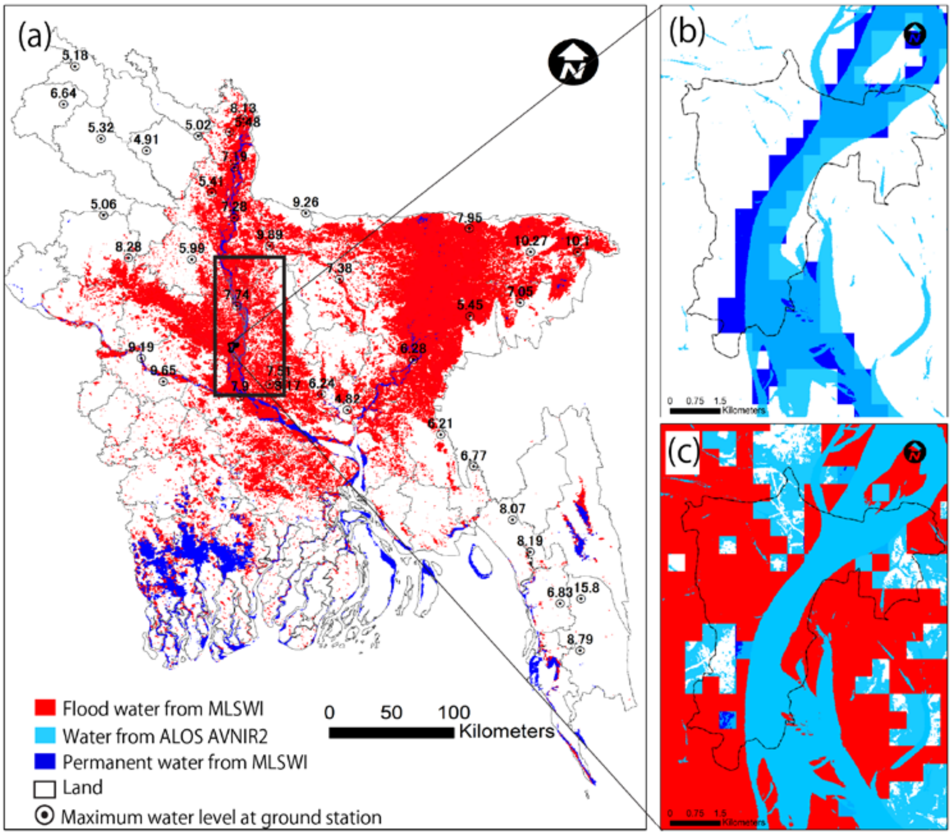

Figure 4. Inundation map based on combination of Terra and Aqua MODIS images (a), and comparison of the permanent water body (blue color) of the Brahmaputra River pre- (b), and post-flood (c) water (red color).

Figure 5 illustrates ALOS AVNIR2 composite images (red=band 4, green=band 2, blue=band 1) before (Figure 5.a) and after (Figure 5.b) flood with NDVI (Figure 5.c) in the Sirajgonj district. These examples show inconsistent flood detection by MLSWI. MLSWI detected some parts of higher land (white color in Figure 5.c), though corresponding to the percentile of mixed spectra area, as flooded though other parts not as flooded. These examples indicate difficulties in flood detection by MODIS with a limited resolution. Besides satellite-based measurement, hydrological gauging stations which record the current maximum water level and flooding stage for monitored river, are the only data source available for providing information on flood status at given points in Bangladesh (Figure 4.a).

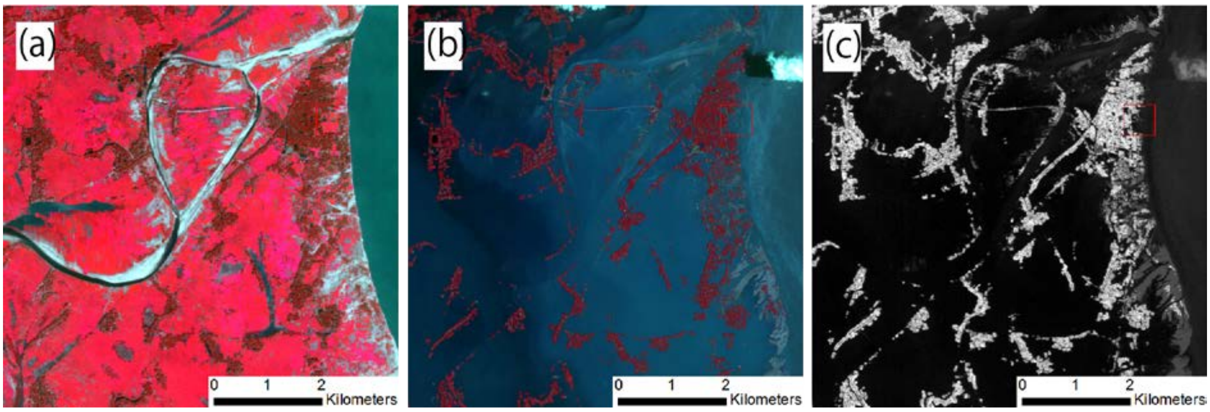

Figure 5. ALOS AVNIR2 composite images (red=band 4, green=band 2, blue=band 1) of pre- (a) and post-flood (b), with NDVI (c) in the Sirajgonj district near the Brahmaputra River.

CONCLUSION

We proposed a flood detection method with a floodwater indices as well as flood inundation mapping technique using MODIS products for the entire country of Bangladesh. This straightforward methodology suggested the possibility of MLSWI to reduce ambiguity in detecting floodwaters. At the same time, we improved the method for greater accuracy in detecting inundation areas. Moreover, the study found that MLSWI can directly detect floodwaters from the source data (reflectance: R) of multi-temporal MODIS during flood events with the starting and ending dates, maximum extent, peak flood, etc. This information can be quickly provided to stakeholders, districts and administrative agencies of their country.

Further studies are needed in order to overcome image resolution and weather problems. The combination of moderated and high-resolution images including SAR (synthetic aperture radar) should be considered to improve the accuracy of flood detection and to acquire both high spatial and high spectral information such as image fusion. Particularly, dynamic flood phenomena can be more accurately reproduced with more information on flood depth, duration and location as well as mapping techniques. In this respect, the MLSWI in this study can contribute to global flood monitoring (e.g. UN, WMO, EU) as well as to near-real-time flood inundation mapping for faster emergency responses with further upgrading.

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