Monitoring Urban Surface Water Bodies Changes Using MNDWI Estimated From Pan-sharpened Optical Satellite Images

Authors: VU Anh Tuan*, LE Thi Thu Hang, NGUYEN Hong Quang
Vietnam National Space Center – Vietnam Academy of Science and Technology

ABSTRACT

There have been numerous studies using the SWIR band of medium spatial resolution satellite scenes such as Landsat, Sentinel-2 to extract the surface water. Using satellite data at morderate resolutions will cause the problem of mixing pixels and result to uncertainty and limitation. To deal with this challenge, this study focuses on evaluation of using pan-sharpened Short-wavelength infrared (SWIR) band of remote sesing imagery for extracting urban surface water bodies. The SWIR is a parameter of the equation to calculate the Modification of Normalized Difference Water Index (MNDWI) and other water indexes. The pan-sharpened Short-wavelength infrared (SWIR) band of the Landsat and Setinel-2 images at the better resolution (as the RGB band of Setinel-2 and panchromatic of Landsat) is used for estimating the water index and improving the accuracy of surface water bodies extracted. In the applying for 10-year time serries of Landsat and Setinel-2 images of Hanoi, this study also investgated the methods of pan-sharpening to figure out how to calculate the MNDWI at the higher accuracy.

Keywords: pan-sharpening, Landsat, Sentinel-2A, Water extraction, Water index

1. INTRODUCTION

Water surface is an important part of the water cycle and surveying and delineating surface water are important in water resource management. In urban area, water surface is a valuable environmental resource as well as economical activities such as tourism and entertainment, fishery. In the environment, it has different functions such as air conditioning, water, flood control, wastewater treatment. However, this resource is facing the situation of rapid urbanization and the migration in urban areas which leads to an increase in the construction density, causing the urban surface water to be narrowed and affected. In term of water quality, this is resulting in many surface water areas being lost or unable to regulate water. Researching and monitoring surface water fluctuations for current management in urban areas and seeking effective approaches to management and protection of surface water are essential.

In case of Hanoi City, lakes are managed by People's Committees of city. However, according to management regulations, the lakes are also managed by many departments from central to local level (Figure 1). This existing complicated system bring many challenges in term of lake management. For example: according to the Hanoi Lake Report 2015 [1]: period (2010-2015) only 6 districts including: Ba Dinh, Hoan Kiem, Ha Ba Trung, Dong Da, Cau Giay and Tay Ho districts, Hanoi 17 lakes have been lost and 7 new lakes have been added and the total area of variation has decreased by 72,540 m^2. This is just the number of urbanized districts that are less volatile than the new districts of Hanoi (Ha Dong, Bac Tu Liem, Nam Tu Liem, Gia Lam ...). Also, according to the Hanoi Lake Report 2015, the current lake management is mainly based on available data which is measured, analyzed, investigated in-situ. This method has high cost, requires a lot of time, does not meet the immediate requirements. In addition, this management method requires many people and especially for a large scale.

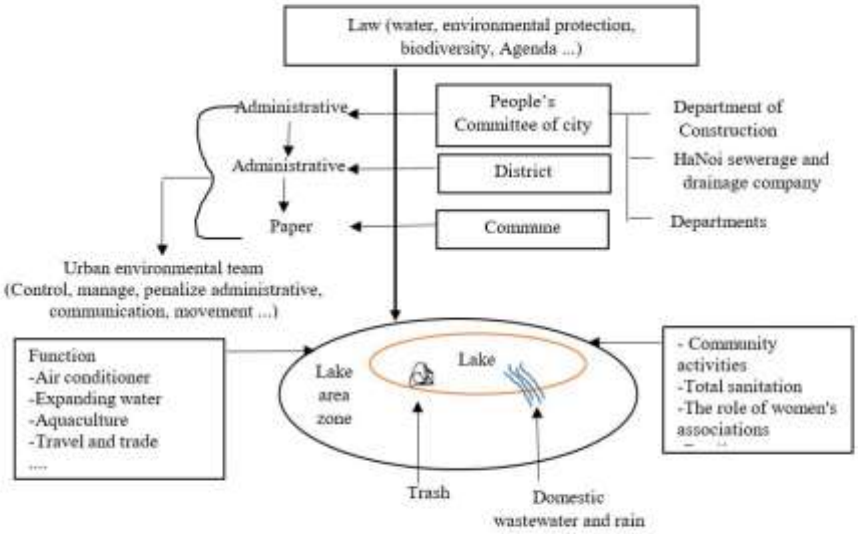


Figure 1. Hanoi lake management system. From Hanoi lake report 2015

Remote sensing can be considered as a tool for solving above disadvantages. Remote sensing data provide a large space, real time, diverse information which is suitable for monitoring and managing surface water fluctuations. Currently, there are many studies and applications using remote sending data for surface water extraction based on water index calculation method. The advantage of the method is user-friendly, cost-effective [2]. Water indices have been calculated and given by McFeeters (1996) provides a water difference index (NDWI) [3] using green and near infrared (NIR) bands of satillite images. This index is calculated based on the phenomenon of water surface with strong absorption and low radiation for these two bands within range from visible waves to infrared. The NDWI index is able to enhance water information to identify and extract it effectively in most cases. Since it is also highly sensitive to the soil, the result is often mixed with construction soil and water surface. In order to mitigate the disadvantages of NDWI, Xu (2006), on the basis of NDWI, gave a different index, MNDWI [4] which uses shortwave infrared band (SWIR) to replace the NIR band used in the NDWI calculation formula. The MNDWI index has been tested in numerous studies that it is more likely to enhance water information so that the water surface can be extracted more accurately [5].

In recent decades, MNDWI has been widely used to produce surface water maps at different scales. Therefore, the spatial resolution of two Green bands and the SWIR band directly affects the water extraction accuracy. Many applications extracted water from satellite images such as Carroll et al. (2009) created a global water surface image at a resolution of 250m [6], Feng et al. (2012) used MODIS images from 2000 to 2010 to estimate changes in water changes in Poyang [7], Rokni et al. (2014) used Landsat TM images, ETM + and OLI extract and changes surface water objects [8]. In comparison with MODIS, Landsat and Sentinel images have much better resolution. They can extract clear and relatively precise surface water boundaries. However, the accuracy for water extraction bands of 30m, 20m is not enough to identify small water areas, especially surface water areas in urban areas. In order to get higher accuracy, MNDWI index with higher resolution (10m for sentinel images and 15m for Landsat images) is calculated from resolution enhanced of SWIR and green bands. Commonly, there are two methods to enhance the resolution of remote sensing images: spatial interpolation and image mixing. The spatial interpolation method is usually applied to low spatial resolution images and does not use any additional data. The image mixing method is based on the higher spatial resolution available band to enhance the resolution for a lower image bands. This method is widely used for remote sensing image such as MODIS, Landsat TM/ETM, SPOT ...and has been applied by many surface water extracting studies. Feng et al. (2012) used image mixing method of PCA and IHS to produce surface water map with 250m resolution from MODIS image with spatial resolution of 250m and 500m to estimate changes in flooding of Lake Poyang [7]. For the urban environment, the higher spatial resolution satellite image is required in order to get better accuracy in surface water extraction. Accordingly, similar method of Feng et al. (2012) is applied for Sentinel-2 (10m spatial resolution) and Landsat (TM/ETM/OLI) (15m spatial resolution in panchromatic band) in this study. As a result, this study found that the MNDWI index calculated from enhanced spatial resolution bands is suitable for medium resolution satellite images.

2. STUDY AREA AND DATASET

2.1. Study area

The lakes are part of the ecological system and landscape of Hanoi, the capital of Vietnam. The city, in the process of expanding and becoming a big and modern city, cannot avoid fast land use change, including lakes. Naturally, the land use change in Hanoi is mostly occurred in urbanization area. Hence, the study area is focused on urban districts and two rural districts (Thanh Tri and Gia Lam) with fast development and urbanization.

Figure 2. Study area

2.2. Data

Data used in this study include: Landsat, Sentinel-2 satellite images for 10 years from 2008-2017, 01 image every year with cloudless and clearest images. Landsat 5 (2008-2011):

images Landsat 5 used in this study on August 7, 2008; November 5, 2009; November 8, 2010; September 24, 2011; with cloudless conditions with 07 spectrum bands with a spatial resolution of 30m; which uses 03 visible bands; band 1 (blue); band 2 (green); band 3 (red) and band 5 (swir) in water extraction and monitoring; Landsat 8 (2013-2017): December 7, 2013; January 18, 2014; July 11, 2015; 1/6/2016; July 4, 2017 with cloudless conditions including 11 spectrum bands with spatial resolution of 30m and 15m; Which uses three visible bands, band 2 (blue); band 3 (green); band 4 (red) and band 5 (nir); Band 6 (swir) bands with a resolution of 30m and band 8 (pan) with a resolution of 15m. Images Sentinel-2 (2015-2017): October 6, 2016; October 31, 2017 with cloudless conditions; there is little cloudiness on October 22, 2015; Data includes 13 spectrum bands with many different resolutions. However, only three visible bands are used 2,3,4 (Blue, green, red) and one band 8 (NIR) with a resolution of 10m; 02 bands 11,12 (SWIR) with a resolution of 20m

3. METHOD

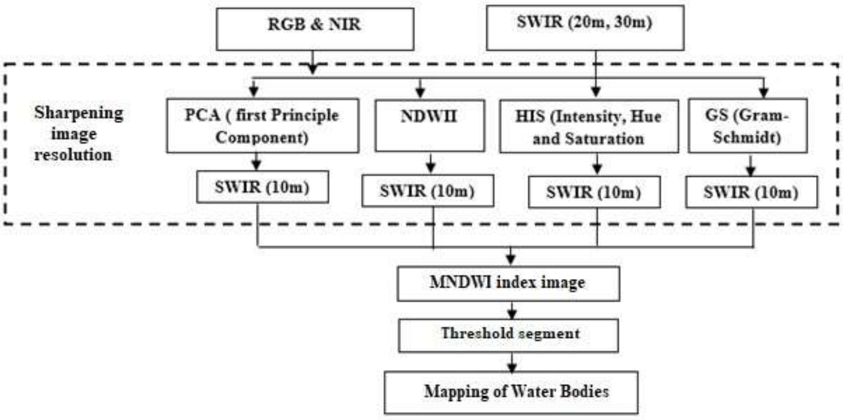


Figure 2. Workflow of sharpening image resolution and surface water extraction

3.1. Nomal Difference Water Index (NDWI):

$$NDWI = \frac{\rho_{green} - \rho_{NIR}}{\rho_{green} + \rho_{NIR}} \qquad (3.1)$$

The formula (3.1) uses two green and NIR bands to maximize the reflectivity of the water surface in the green band and minimize the reflectance of water body in the NIR band.

$$MNDWI = \frac{\rho_{green} - \rho_{SWIR}}{\rho_{green} + \rho_{SWIR}} \qquad (3.2)$$

Xu's Modified NDWI (MNDWI) has replaced the NIR band used in formula (3.1) into SWIR band. In general, surface water values in MNDWI are often greater than those in NDWI because the water body has a stronger absorbability in the SWIR band than that in the NIR band and objects such as soil, plants or earthen construction are smaller (often negative) because they reflect light in SWIR rather than green. MNDWI has proven its superiority in many water-related applications.

In this study, we also tested images with the both indicators for the study area and found that the ability of MNDWI to identify and separate water for the same study was superior to NDWI, Therefore, the study used MNDWI index to extract water as the final result.

3.2. Pan-sharpened Satellite Images

Pan-sharpened satellite images to enhance the resolution of the image band is very useful in identifying and extracting water, making it easier to determine the water boundary. There are many methods to pan-sharpen image resolution [9] have been given, in this study using some popular algorithms such as: PCA; HIS; GS often uses NDVII index images to pan-sharpen image resolution for bands of Landsat images and sentinel-2 images (Figure 3). Each method is based on basic principles and has their own advantages and disadvantages [10].

After pan-sharpening the resolution of the bands according to the above methods with the study area, HIS method shows the sharpness, accuracy, preservation of consistency of the characteristics of the spectrum before and after the pan-sharpen. Spectral characteristics of multi-spectral data at low resolution are preserved in high resolution. Therefore, HIS image method is used in this study to pan-sharpen image resolution for water index calculation and surface water extraction (Figure 4).

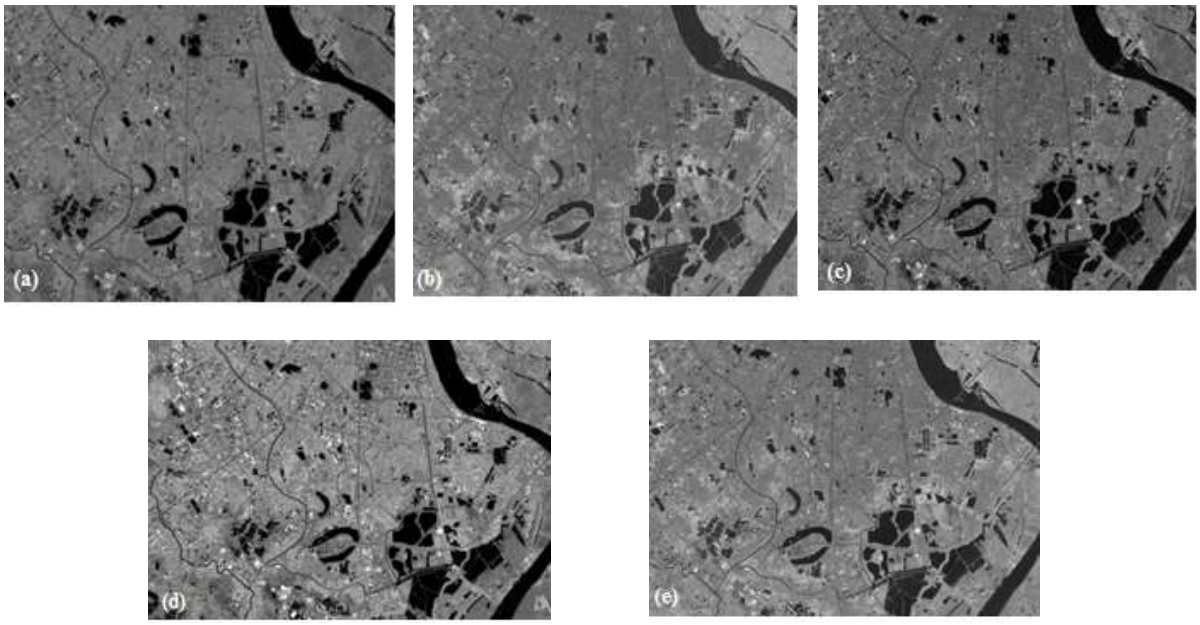


Figure 3. Results of different methods of sharpening SWIR band sentinel-2 image from 20m resolution to 10m, (a) SWIR band with a resolution of 20m; (b) GS method (Gram-Schmidt); (c) IHS method; (d) method of using NDVII; (e) PCA method

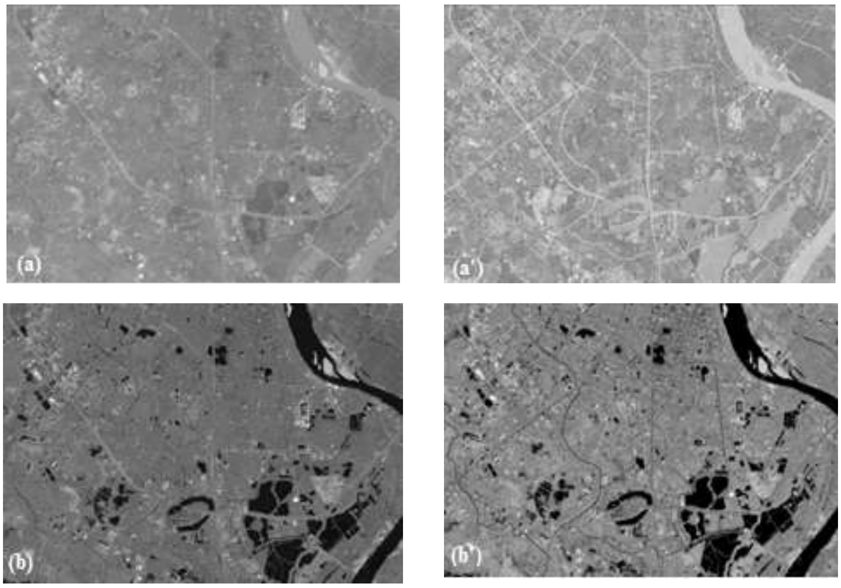
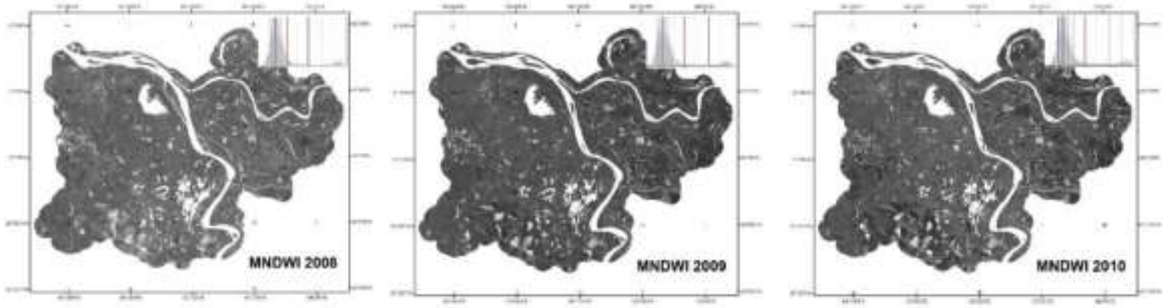


Figure 4. Results before and after sharpening Landsat 8 images from 30m resolution to 15m (a) (a '): band 3 (green) before and after sharpening; (b) (b ') band 6 (SWIR) before and after sharpening

3.3. Image index and threshold segment

Calculate the MNDWI index image according to the formula (3.2.) With bands that have been sharpened according to HIS method for the years 2008-2017. The received MNDWI index images of the years clearly show the difference between water and non-water objects (Figure 5).

To get the difference of water surface and other objects, the pixel value of the water surface can be extracted using fair value thresholds. Selection threshold is the key to extract water from the water index image. The threshold value is chosen from the analysis of various sources of information: histogram shape, entropy, similar characteristics, spatial correlation, gray-scale…. In this study, characterization of the gray-scale diagram according to Otsu's method [11] is used. This method provides a threshold classification based on the shape of the diagram for surface water extraction, analysis of distribution of gray-scale diagrams (Figure 5), comparing threshold adjustment to finally give a reasonable threshold for the region. Research: with selected Landsat pixel image is water with value> 0.12; With the Sentinel-2 pixel image is water with value > 0.4



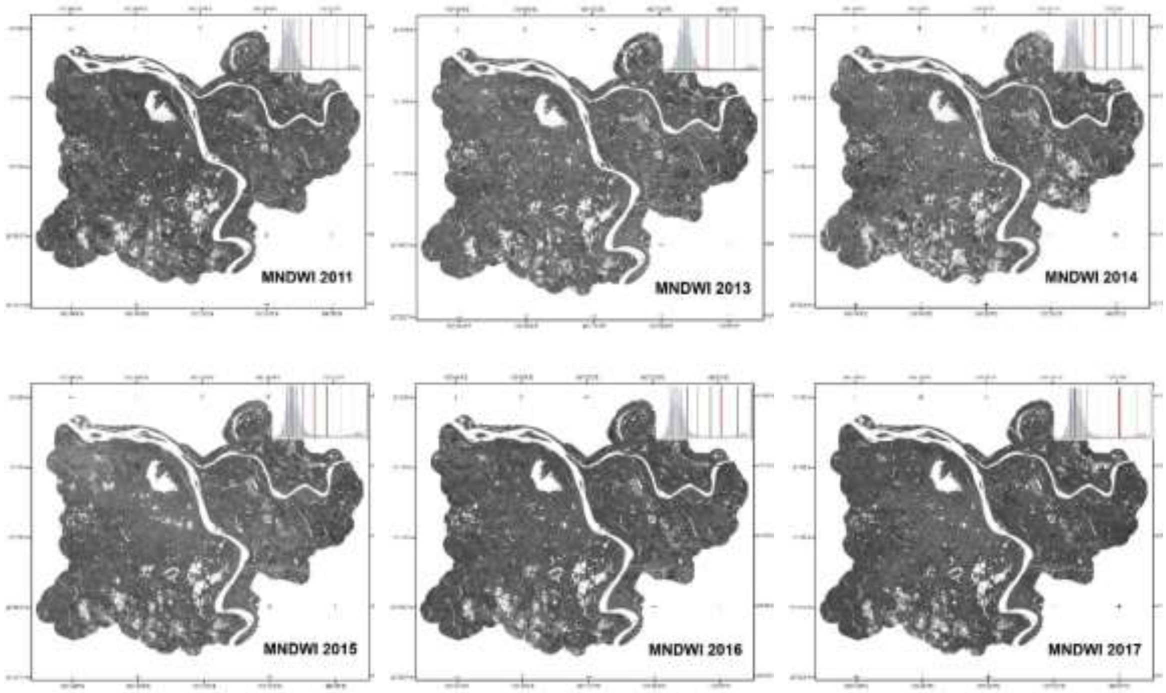


Figure 5. MNDWI water index image with adjusted thresholds. The sub-image in the right-up shows the grey histogram of the image and the red line indicates the obtained threshold in the period of 2008-2017

4. RESEARCH RESULTS AND DISCUSSION

4.1. Mapping of Water Bodies

With the sharpening method of image resolution and analytical thresholds, the research team accurately extracted the water body from satellite images of the years 2008-2017 (Figure 6 and 7). Almost typical lakes in the study area are extracted with the threshold value given.

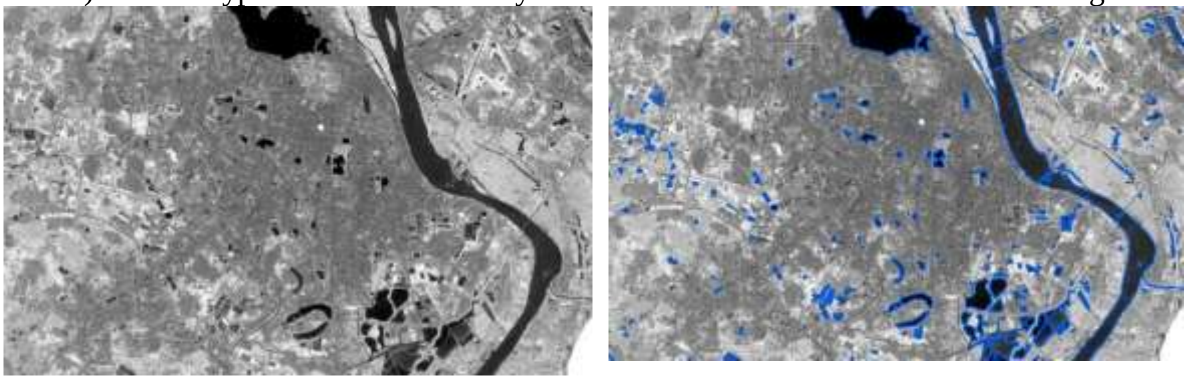


Figure 6. Extracting water from MNDWI index image (sentinel-2 image) with pixel value threshold> 0.4

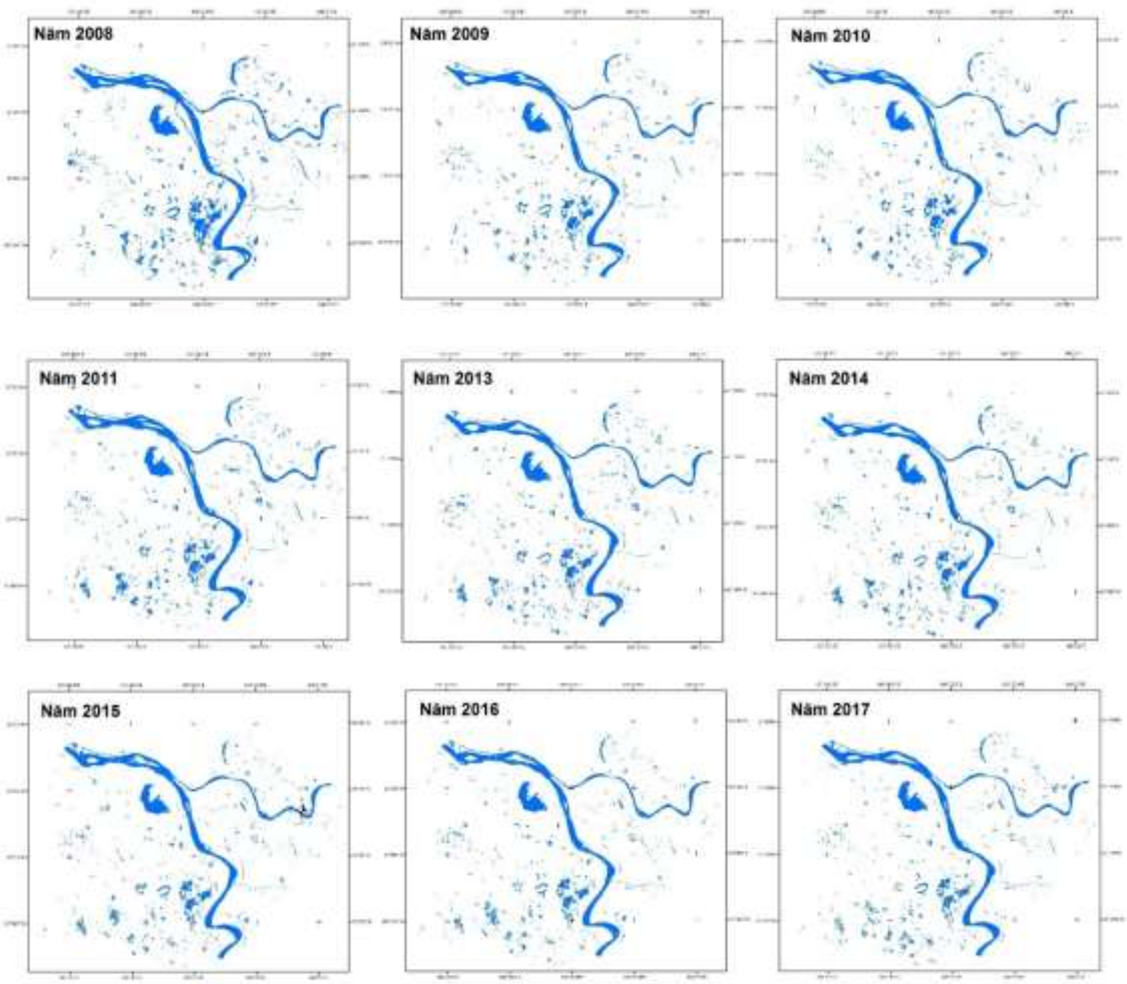


Figure 7. Map of surface water extraction from the MNDWI index image for the period of 2008-2017

4.2. Compare results with report of water body in Hanoi 2015

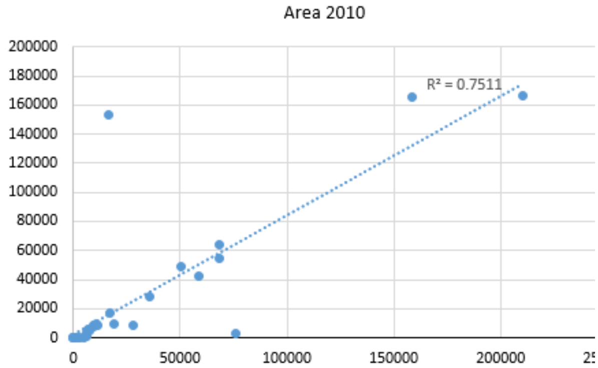
Table 1. Comparison of water body extraction results from satellite images with Hanoi water body report 2015

No	Lake	District	The report of Hanoi Lake in 2015		Satellite Images		No	Lake	District	The report of Hanoi Lake in 2015		Satellite Images	
			Area 2010 (m2)	Area 2015 (m2)	Area 2010 (m2)	Area 2015 (m2)				Area 2010 (m2)	Area 2015 (m2)	Area 2010 (m2)	Area 2015 (m2)
1	Ho Truc Bach	Ba Dinh	158,453	158,453	165,600	161,900	24	Ho Thien Quang	Hai Ba Trung	58.686	58.686	42.400	36.300
2	Ho Thanh Cong	Ba Dinh	50,046	50,046	48,700	48,500	25	Ho Quynh	Hai Ba Trung	7,201	7,201	4,800	2,800
3	Ho Ngoc Khanh	Ba Dinh	35,881	35,881	27,900	22,369	26	Ho Quang Trung	Hai Ba Trung	10,736	10,736	9,800	8,432
4	Ho Giang Vo	Ba Dinh	68,300	38,300	54,900	63,635	27	Ho Hai Ba Trung	Hai Ba Trung	11,415	11,415	8360	9500

5	Ho Dam Tron	Ba Dinh	9,536	9,536	8,650	8,600	28	Ho cong vien Tuoi Tre	Hai Ba Trung	17,302	17,302	17,214	16,457
6	Ho Bach Thao 2	Ba Dinh	5,906	5,906	3,900	4,500	29	Ho canh ho Ao Ca Bac Ho	Hai Ba Trung	6,304	6,272	1,283	1,243
7	Ho Bach Thao 1	Ba Dinh	6,679	6,679	5,490	5532	30	Ho ca Bac Ho	Hai Ba Trung	27,709	18,944	18,100	11,000
8	Ho Thu Le	Ba Dinh	68,521	68,521	63,635	60,247	31	Ho Bay Mau	Hai Ba Trung	210,270	210,270	166,500	159,140
9	Ho Dam	Ba Dinh	9,536	9,536	7,213	8,156	32	Ao Ngo 153/34 Vinh	Hai Ba Trung	19,257	7,275	15,000	3,200
10	Ao Chua mot Cot	Ba Dinh	202	202	NA	NA	33	Ho Thanh Nhan	Hai Ba Trung	76,000	76,000	63,200	52,900
11	Ho Trung Kinh	Cau Giay	NA	4299	NA	2,200	34	Ho Can	Hai Ba Trung	16,325	16,325	152,800	155,700
12	Ho Trung Kinh	Cau Giay	4,078	4,078	NA	3,822	35	Ho Van Chuong	Dong Da	13,418	13,418	15,400	13,403
13	Ho Q.Uy Cau Giay	Cau Giay	2,814	2,814	NA	2,533	36	Ho Nam Dong	Dong Da	42,876	42,876	31,500	33,300
24	Ho nghia trang	Cau Giay	10,533	10,533	10,800	9,400	37	Ho Linh Quang	Dong Da	22,700	22,108	12,900	11,100
15	Ho Nghia Tan	Cau Giay	43,706	43,706	29,700	33,600	38	Ho Lang Thuong	Dong Da	14,797	14,797	11,100	17,000
16	Ho cong vien cau	Cau Giay	NA	43,053	NA	40,111	39	Ho Ho Me	Dong Da	10,061	10,061	10,700	12,600
17	Ao doi dien NT	Cau Giay	24,276	22,935	17,200	20,456	40	Ho Hoang Cau	Dong Da	135,100	135,100	16,200	15,700
18	Ho Tu Lien	Tay Ho	26,446	25,579	32,703	34,306	41	Ho Ba Mau	Dong Da	43,448	43,448	22,800	33,900
19	Ho Tay	Tay Ho	5,160,000	5,160,000	4,986,000	4,965,900	42	Ho Hoan Kiem	Hoan Kiem	120,000	120,000	93,600	92,400
20	Ho Quang Ba	Tay Ho	62,194	30,496	67,125	23,600	43	Dam sen Quang ba	Tay Ho	34,452	33,070	30,756	15,970
21	Dam Tri	Tay Ho	61,490	61,490	47,700	56,126	44	Dam Bay	Tay Ho	57,135	57,135	37,477	43,362
22	Dam Sen Quang Ba	Tay Ho	39,305	39,305	32,547	29,062	45	Ao chua Pho Linh	Tay Ho	23,565	23,565	23,382	22,014
23	Ao Lang	Tay Ho	8,596	8,062	7,321	8,608	46	Ao chua Ba Gia	Tay Ho	3,543	4,580	3,289	2,872

The results of calculating the surface water area from the extraction of satellite images compared with the statistics reported in Hanoi Lake 2015 (Table 1) found that the obtained results have similarities, the correlation coefficients (R^2) were acceptable (Figure 8).

Large lakes are very well extracted, from satellite images. In contrast, small lakes (<4000 m^2) were classified at low accuracy due to medium image resolution were used and is easily confused with pictures of houses and trees in urban areas



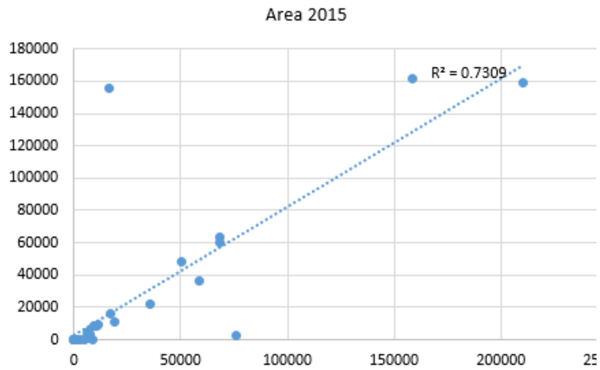


Figure 8. Correlation coefficient between satellite-based lake areas and data in Hanoi lake report 2015

4.3. Influence the shadow of the house, the plant element on the water surface to extract the surface of the water

In urban areas, the spectral values between water and other dark objects (shadow of the house, shade tree, vegetation cover on the water surface) are difficult to distinguish them from each other. This study used methods to interpret and exclude those objects based on the shape of the object, reference time series (Figure 10), referring to the RapidEye image with 5m resolution (Figure 9), and natural combination color.

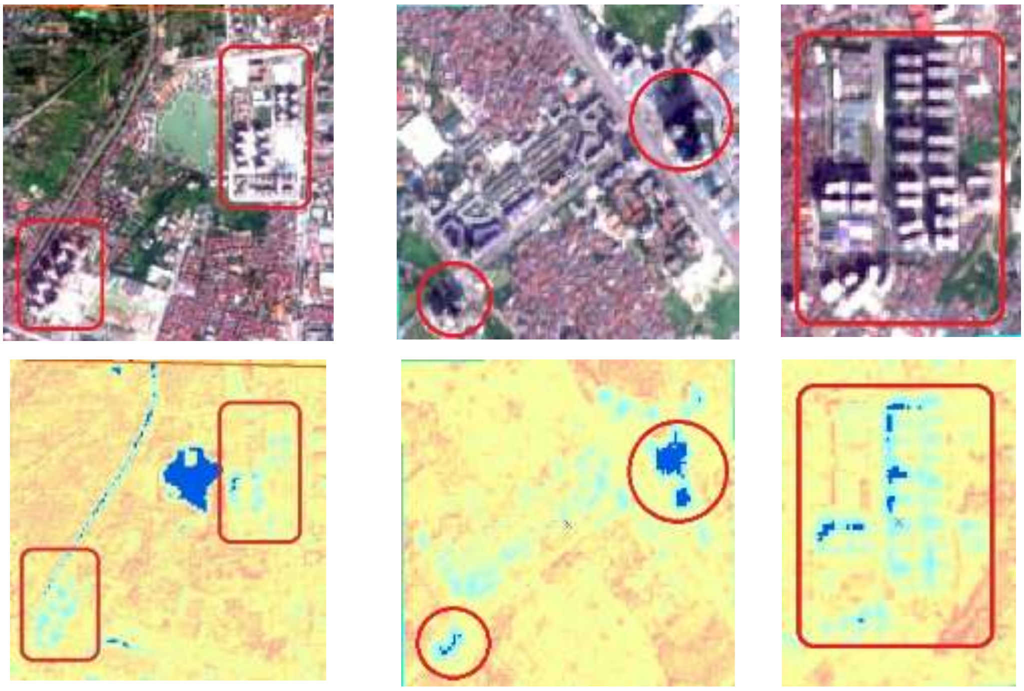


Figure 9. RapidEye image resolution of 5m (above), MNDWI index image (below): using RapidEye image to exclude house shadow

Figure 10. Natural color composite images (above) and MNDWI index images (below): Vegetation covers the lake surface in 2015 so the MNDWI index image does not extract lake surface water; Observing natural images and MNDWI index images of 3 years 2014, 2015, 2016 we can extract the surface water of that lake

4.4. Change of water surface

According to the report of Hanoi Lake in 2015, many changes were reported compared to the report in 2010. The number of lost lakes were 17 led to the lost area of122,540 m^2 and 7 new ones were created resulted in 49,198m^2 lake added (Figure 11). To assess this issue, we reviewed and monitored the surface water changes of the study area within 10 years from 2008 to 2017 and found that In this period, there was a rapid expansion and development of Hanoi capital, and the surface water has changed greatly (Figure 11 and 12). Therefore, we might conclude that the method used could provide useful data, and enable to review, manage and evaluate the changes of surface water in urban areas in general.

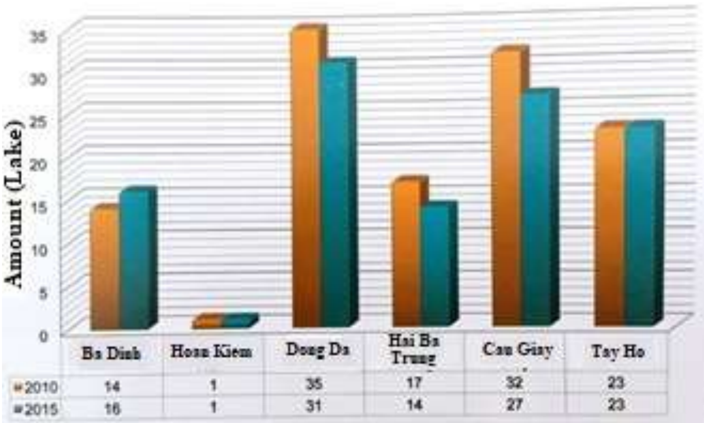


Figure 11. The change in the number of lakes in Hanoi 2010-2015.
From Hanoi Lake Report 2015

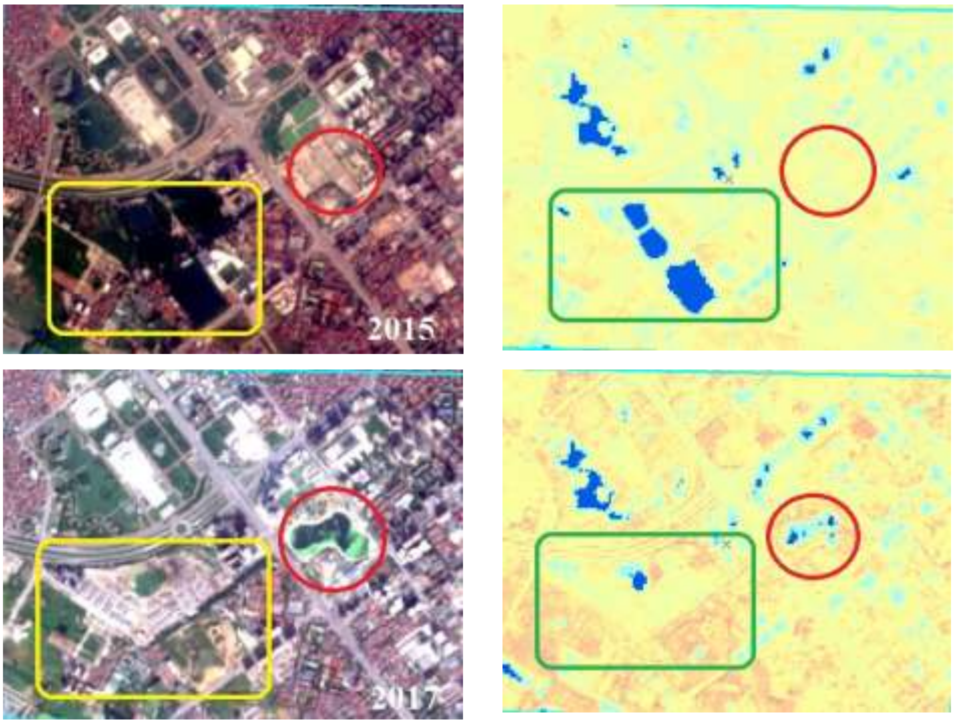


Figure 12. RapidEye image resolution 5m (left), MNDWI index image (right): add lake (red); lost lake (green, yellow)

5. CONCLUSION

The main target of this study is to use, optimize the spectrum bands with better resolution of Sentinel-2 images and Landsat images to sharpen the resolution for SWIR bands, and thereby calculating and extracting the water body more accurately. In popular sharpening methods such as PCA, HIS, GS and NDWII for the study area, the IHS method was excelled and produced the most accurate MNDWI water index image. In addition, the research team selected the optimal threshold for the study area to establish surface water maps, and the results were compared with the data reported in Hanoi Lake 2015 and found them to be highly similar. Therefore, this method can be used for fast and continuous monitoring with key areas especially in urban areas.

The ability to identify water with index images and selection thresholds is relatively good. However, this threshold has been only tested with the study area, not consulted and tested with other areas. In addition, in urban areas, the spectral values between water and other dark objects (house shadows, tree shadows, vegetation cover on surface water ...) are sometimes challenging to distinguish. It is very difficult to identify and remove these elements, it is needed to add processing to get better results. In this study, we proposed and used several methods to eliminate such objects: eliminating the shadow of the house, the shadow of the tree based on the shape, size, position of the object, tracking the data series. Over the years to exclude, refer to higher resolution images such as RapidEye image with 5m resolution, even using the natural color composite image of the originals used to guess the excluded reading. Seasonally, for lakes with covered vegetation (such as lotus, duckweed ...) they can be excluded using photo series of different years or months.

In summary, the method of enhancing image resolution significantly improved water extraction ability for moderate resolution images such as Landsat and Sentinel-2 images. This study offers the choices of precise water extraction techniques, and are suitable for water monitoring in general and urban areas in particular over many periods of time.

6. ACKOWNLEDGEMENT

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8. CONTACTS

* Author to whom correspondence should be addressed

- Name: VU Anh Tuan
- Institution: VietNam National Space Center, Vietnam Academy of Science and Technology (VAST)
- Address: Building A6, 18 Hoang Quoc Viet, Cau Giay District
- City: Hanoi
- Country: VIETNAM
- Tel. +84 0989096171
- Email: vatuan@vnsc.org.vn
- Web site: www.vnsc.org.vn

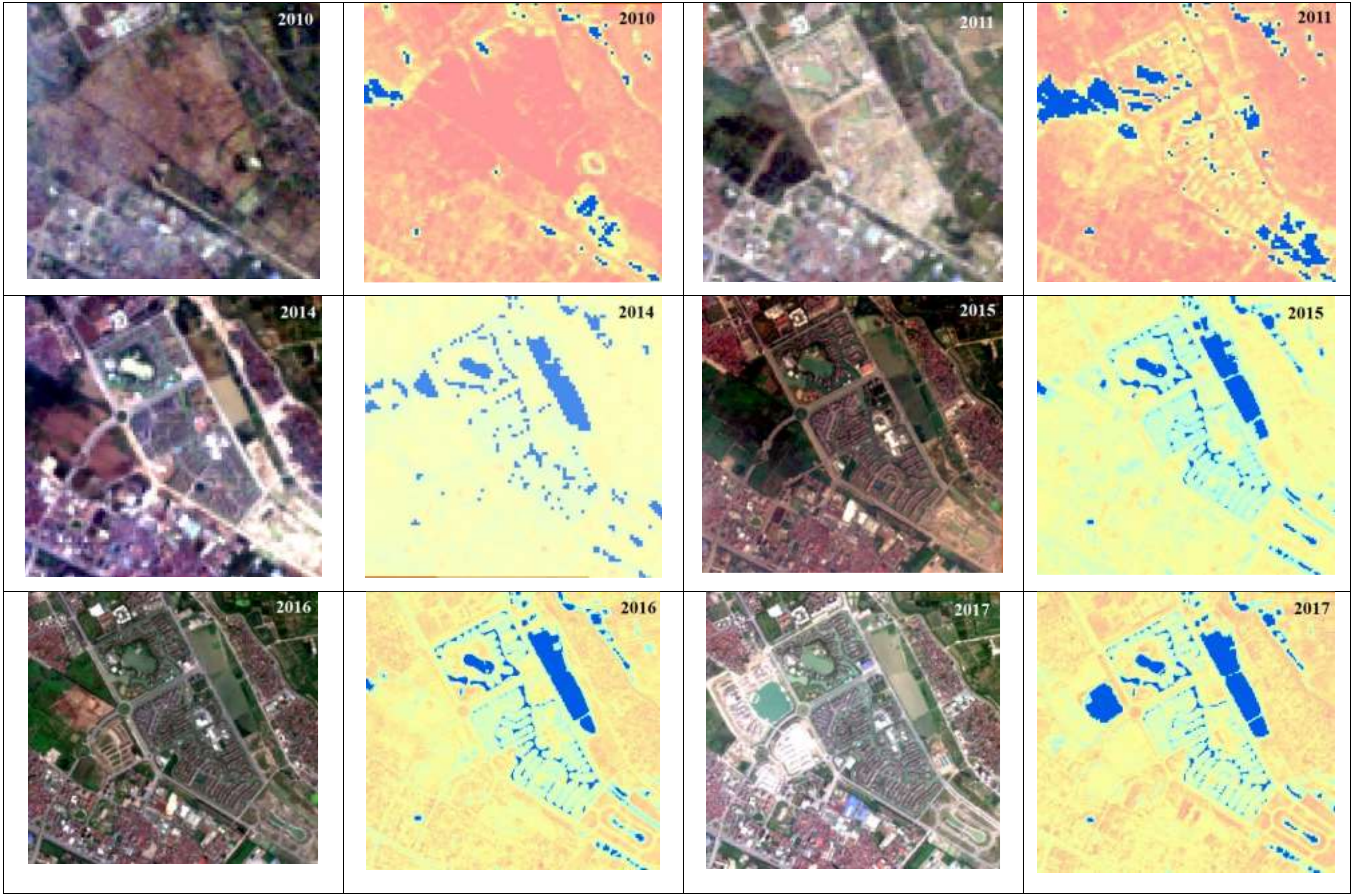

Figure 15. Natural color composite images (left), MNDWI index images (right): Change in surface water body of VINHOMES RIVERSIDE urban area Long Bien district in the period of 2010-2017