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

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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 moderate 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 sensing 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 Sentinel-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 series of Landsat and Setinel-2 images of Hanoi, this study also investigated 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 m². 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.

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 satellite 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

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

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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](image)

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

![Workflow of sharpening image resolution and surface water extraction](image)

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

### 3.1. Normal Difference Water Index (NDWI):

\[
NDWI = \frac{\rho_{\text{green}} - \rho_{\text{NIR}}}{\rho_{\text{green}} + \rho_{\text{NIR}}}
\]

(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.

\[
MNDWI = \frac{\rho_{\text{green}} - \rho_{\text{SWIR}}}{\rho_{\text{green}} + \rho_{\text{SWIR}}}
\]

(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](image-url)
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.
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
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

<table>
<thead>
<tr>
<th>No</th>
<th>Lake</th>
<th>District</th>
<th>The report of Hanoi Lake in 2015</th>
<th>Satellite Images</th>
<th>No</th>
<th>Lake</th>
<th>District</th>
<th>The report of Hanoi Lake in 2015</th>
<th>Satellite Images</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Area 2010 (m²)</td>
<td>Area 2015 (m²)</td>
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<td></td>
<td>Area 2010 (m²)</td>
<td>Area 2015 (m²)</td>
</tr>
<tr>
<td>1</td>
<td>Ho Truc</td>
<td>Ba Dinh</td>
<td>158,453</td>
<td>158,453</td>
<td>24</td>
<td>Ho Thien Quang</td>
<td>Hai Ba Trung</td>
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<td></td>
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<td>165.600</td>
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<td></td>
<td>42.400</td>
<td>36.300</td>
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<tr>
<td>2</td>
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<td>50,046</td>
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<td>Hai Ba Trung</td>
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<tr>
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<tr>
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<td></td>
<td></td>
<td>8360</td>
<td>9500</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Area 2010</th>
<th>Area 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image_url" alt="Graph" /></td>
<td><img src="image_url" alt="Graph" /></td>
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</table>

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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 8. Correlation coefficient between satellite-based lake areas and data in Hanoi lake report 2015
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 of 122,540 m² and 7 new ones were created resulted in 49,198 m² 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.
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. ACKNOWLEDGEMENT

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7. REFERENCES


8. CONTACTS

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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