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# Monitoring the trophic state index of Linh Dam Lake using Landsat 8 Imagery

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ABSTRACT

*Monitoring quality of water of the lakes is a critical task towards better environmental management. The trophic state index (TSI) is one of important water quality parameters which represents the trophic state of a waterbody. This work proposes a method for monitoring the TSI based on the remote sensing retrieval of chlorophyll-a concentration (Chla) in the lake water. For that, in-situ reflectance data measured in Linh Dam Lake (in Hanoi) was resampled to match ratio of Landsat 8 band 3 versus band 2 and linear regression analyzed with concurrent measured Chla. The ratio of Landsat 8 band 3 versus band 2 provided the best fit model with TSI retrived from measured Chla ($R^2$ value of 0.78). The model was higly matched up with validation Chla data measured on April 1st and 2nd 2017. Resultant time-series map of TSI for Linh Dam Lake show an increasing trend of TSI over time from 2013 to 2016. Accordingly, trophic state of Lake Linh Dam changed from eutrophic level in 2013 to hypertrophic level in 2017. In space, TSI is high along the lake shore where located local sullage pits and decreaded gradually towards lake's center. Methods used in this work can be extent to monitor TSI for numerous urban lakes in Hanoi.*



## 1. Introduction

Satellite imagery has been successfully used to estimate water quality over last 40 years (Gholizadeh et al. 2018). Multispectral image applications for water quality monitoring are based on the relationship of the water optical properties with water quality parameters such as total suspended sediment, water clarity as well as chlorophyll - a concentration (Chla) (Jensen, 2000; Patra et al., 2016).

Eutrophic lakes exhibit poor water quality unsuitable for freshwater supply, human health, fisheries and recreation (Hammer and Mackichan, 1981). Eutrophic level of a lake can be assessed using the trophic state index (TSI). Carlson (1977) proposed the calculation of the lake TSI by using lake Secchi disk depth (SDD), Chla and total phophorus concentration. Among them, Chla is the major indicator of trophic state because it acts as a link between nutrient

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concentration and algae production which is directly related to eutrophication phenomena (Montanaro et al., 2014). Many studies have demontrated that increasing of Chla causes an increase in spectral response at green and near-infrared wavelengths (Schalles, 2009). Based on that principle, numerous studies have been suscessffuly using satellite images to determine Chla in inland waters. Consequently, using satellite image for estimate the TSI is a possible and promissing application (Membrillo-Abad et al., 2016)

Landsat data is free of charge and has very long time series of archived data which can provide insight about historical events or developments in an area and therefore can be utilized for monitoring purposes. Previous studies show that Landsat has been proven as a high capability data for monitoring water quality in lake waters (Lathrop, 1986; Lathrop, 1992; Dekker et al., 1996; Hellweger et al., 2004; Han and Jordan, 2005; Mancino et al., 2009). With spatial resolution of 30 m, Landsat data provides an optimal tool for monitoring lake water quality in urban areas where most lakes are impacted highly by urbanization, often under high trophic states and sensitive to algae blooms. The new Landsat, Landsat 8, has first launched on March 18, 2013 providing opportunity for continuing the water quality monitoring by using Landsat data series. Although Landsat 8 was not designed for water environment, this data has been successfully exploited for estimating Chla in lake waters (Lim and Choi, 2015; Zhang and Han, 2015; Kim et al., 2015, Ha et al., 2017). Additionally, temporal and spatial resolutions of Landsat 8 and its easy accessibility can be main reasons to select this sensor for Chla estimation in near future.

In this study, we proposed an accurate method to monitor the TSI of Lake Lind Dam and the TSI seasonal variation using Landsat 8 data based on an estimation of Chla. Linear regression was carried out on *in-situ* Chla and water spectra measured concurrently with Landsat 8 acquiring data to generate a model for estimation of the lake's TSI. Multidates Landsat 8 images then were used to estimate the seasonal variation of TSI of Lake Linh Dam that provided an obvious database to generate the impact of local natural and social factors such as climate features, surrounding urbanization on the lake trophic state in the future.

## 2. Materials and methods

### *2.1. Study area*

Lake Linh Dam is located in the Southern part of Hanoi city, in Hoang Liet ward, Hoang Mai district (Fig. 1). The lake has an oxbow shape which was an original part from To Lich River and is surrounded by a compacted residential area, the Linh Dam Resident Area. The main role of Lake Linh Dam is for flood regulating, not for waste-water containing. However, due to rapid urbanization of surrounding area, Lake Linh Dam is threatened by eutrophication and pollutants from household garbage (Family E-Journal, 2016). Similar to other lakes in Hanoi urban, Lake Linh Dam was classified as a high trophic level waterbody (INCO-DEV, 2005) with total nitrogen and total phosphorus reached to 22.2 mg/L and 2.55 mg/L, respectively, in 2002 when the Linh Dam Urban Area had not built yet. Since 2002 up to present, no publication addressed directly the water quality of Lake Linh Dam, therefore it is lack of evident data to assess the impact of surrounding urbanization on the lake water.

### 2.2. Water spectral measurement and sampling

Field spectra were measured using a portable Field spectra GER 1500 spectroradiometer, with a spectra sampling of 1.5 nm and spectra resolution of 3 nm with above-water measurement method protocol (Mueller et al., 2003). The instrument was held in a nadir viewing geometry to approximate the viewing geometry of Landsat at 0.5 m above the water surface. Observations were made between 09:30 and 13:30 to ensure good illumination conditions and minimize variability in diffuse sky irradiance. Spectral reflectance of water was calculated using the following eq:

$$R_w(\lambda) = \rho_p(\lambda) \cdot \frac{L_t(\lambda) - rL_{sky}}{L_p(\lambda)} 100 \quad (1)$$

where $R_w(\lambda)$ is spectral reflectance of water (%); $\rho_p(\lambda)$ is the reflectance of the reference

panel; $L_t(\lambda)$ is the radiance of surface water at the measurement point; and, $L_p(\lambda)$ is the radiance of the reference panel, $r$ is the air-water-interface reflectance with a value of 0.022 in clear-sky condition (Moley, 1999), $L_{sky}$ is the radiance of sky which measured by the difference of water radiance measured at the same Sun azimuth and zenith of 40°.

The *in situ* water sampling was performed on the prefixed dates when Landsat satellite overpassed the Hanoi region. The water sampling procedure was done on 6 dates: June 1st, 2016; September 28th 2016, April 1st and 2nd 2017 April 16th and 17th 2017. 40 water samples in total were collected over the entire lake surface area with a Global Positioning System (GPS) receiver used to locate the points as shown in Fig. 1. At each sampling point, surface water sample was collected at 0-20cm depth in 500mL cleaned dark-color bottles, stored at a constant temperature of 4°C and then transported to the laboratory.

The concentration of Chla was determined by standard spectrophotometric method using the Hach DR 5000 in 90% acetone extraction. The water sample was filtered, followed by acetone extraction to estimate Chl-a and measure the absorbance of the extracted dye at 663, 645, 630, and 750 nm. Finally, Chl-a concentration was calculated as per APHA (APHA, 1998) using formula (2):

$$Chla = \frac{11.85 \cdot (E_{664} - E_{750}) - 1.54 \cdot (E_{647} - E_{750}) - 0.08 \cdot (E_{630} - E_{750})}{\frac{1}{d} \cdot \frac{100 \cdot V_1}{V_2}} \quad (2)$$

where, $E$ is spectral absorption coefficient of the sample at wavelengths; $V_1$ is used acetone volume; $V_2$ is filtered water volume and d is optical transmission length in cuvet 1cm.

In this study, TSI of Lake Linh Dam was calculated based on Chla using Carlson's model (1977) as following equation:

$$TSI = 10 \cdot [6 - \frac{2.04 - 0.68 \cdot (Chla)}{\ln(2)}] \quad (3)$$

### *2.3. Landsat 8 data and image processing method*

Ten cloud-free Landsat 8 satellite images covering Lake Linh Dam were used in the study (Table 1). These Landsat images at path 127, row 45 were downloaded from the archive of USGS's Landsat images (http://earthexplorer.usgs.gov).

All images were provided in GeoTIFF format and geo-referenced to a common UTM coordinate and radiometric correction using method of Schroeder et al., (2006) by Landsat Program before handling to users.

Images were then radiometrically calibrated using available tool in ENVI 5.3 solfware (USGS, 2014) to convert DN value into top-of atmosphere (TOA) reflectances.

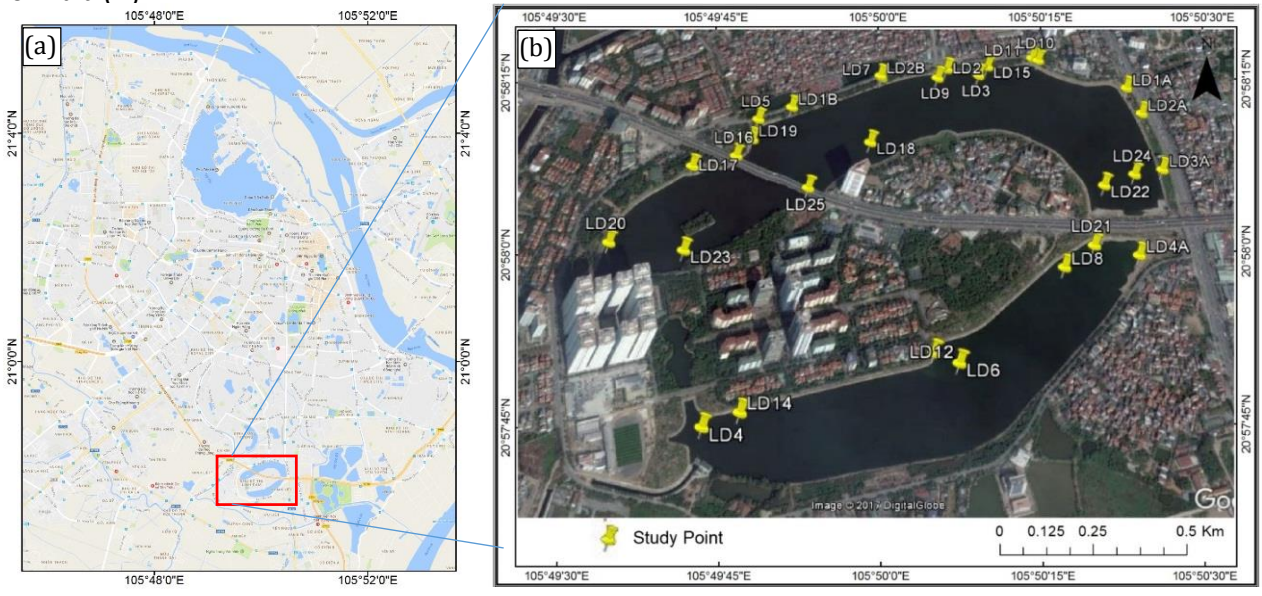


*Figure 1. (a) Location of Lake Linh Dam in Hanoi City and sampling location (b).*

*Table 1. Used Landsat images.*

| No. | Date of acquiring | ID of images | No. | Date of acquiring | ID of images |
|---|---|---|---|---|---|
| 1 | 06/06/2013 | LC81270452013160LGN00 | 6 | 16/05/2016 | LC81270452016137LGN00 |
| 2 | 29/09/2013 | LC81270452013272LGN00 | 7 | 01/06/2016 | LC81270452016153LGN00 |
| 3 | 18/12/2013 | LC81270452013352LGN00 | 8 | 07/10/2016 | LC81270452016281LGN00 |
| 4 | 11/05/2014 | LC81270452014131LGN00 | 9 | 10/12/2016 | LC81270452016345LGN00 |
| 5 | 01/06/2015 | LC81270452015182LGN00 | 10 | 01/04/2017 | LC81270452017091LGN00 |

*Table 2. Descriptive statistics of Chla and its based TSI in Lake Link Dam on six surveyed dates.*

| | June 1st 2016 | | September 27th 2016 | | April 1st 2017 | | April 2nd 2017 | | April 16th 2017 | | April 17th 2017 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Chla | TSI | Chla | TSI | Chla | TSI | Chla | TSI | Chla | TSI | Chla | TSI |
| Minimum | 182.1 | 82 | 113.6 | 77 | 30.9 | 64 | 50.6 | 69 | 30.3 | 64 | 58.3 | 70 |
| Maximum | 304.3 | 87 | 128.3 | 78 | 106.3 | 76 | 114.0 | 77 | 186.0 | 82 | 105.0 | 76 |
| Average | 222.1 | 83 | 121.0 | 78 | 78.1 | 73 | 79.4 | 73 | 84.9 | 73 | 87.4 | 74 |
| No. of samples | 4 | 4 | 2 | 2 | 10 | 10 | 10 | 10 | 7 | 7 | 7 | 7 |

Concurrent water spectral data were used for atmospheric correction of Landsat 8 images. Linear regression model between Landsat 8 TOA reflectance data versus mean of water reflectance at each band region was used to convert the TOA reflectances in image into surface reflectance.

## 3. Results and discussion

### *3.1. Trophic state and water optical feature of Linh Dam Lake*

Table 2 shows statistical parameters of Chla and its based TSI in Lake Linh Dam in different times. According to this data, TSI of Lake Linh Dam ranged from 64 (in April) to 87 in early June. Measured TSI of the lake show a small variation in time, was about 73-74 in average in April, 78 in September, and reached to 83 in June. Based on the trophic scale of Carlson and Simpson (1996), Lake Linh Dam was classified under hypertrophic level with frequent TSI value varied from approximately 70 to more than 80. From this trophic state, Lake Linh Dam water is considered as containing dense algae and very sensitive to algae blooms, particularly in summer when strong sunlight speeds up the photosynthesis process of dense algae in the lake water.

Reflectance spectra measured at surface water of Lake Linh Dam and their corresponding TSI were shown in Figure 2. The figure included also locations of Landsat 8 multispectral bands corresponded to *in-situ* reflectance and TSI data. Accordingly, TSI was not correlated to any single Landsat band reflectance. Water points with low total reflectance (red-tone solid lines) were actually corresponding to high TSI values (82-87), while waters with high total reflectance (green-tone dash lines) corresponding to medium TSI values (74-75).

Reflectance of waters at 900 nm suggests the difference of water turbidity among these observed points (Schalles, 2009), the higher reflectance at 900 nm the higher turbidity water has, and therefore total reflectance in each single band can be upward due to suspended sediment content in water than TSI. As a result, no Landsat single band data was used to estimate TSI.

Because TSI has positive correlation with Chla (TSI was calculated by Chla using the first order linear function) while Chla has been widely estimated using band ratios in blue-green or red-near infrared regions, therefore relationships between TSI and surface water reflectance ratios in these regions were investigated.

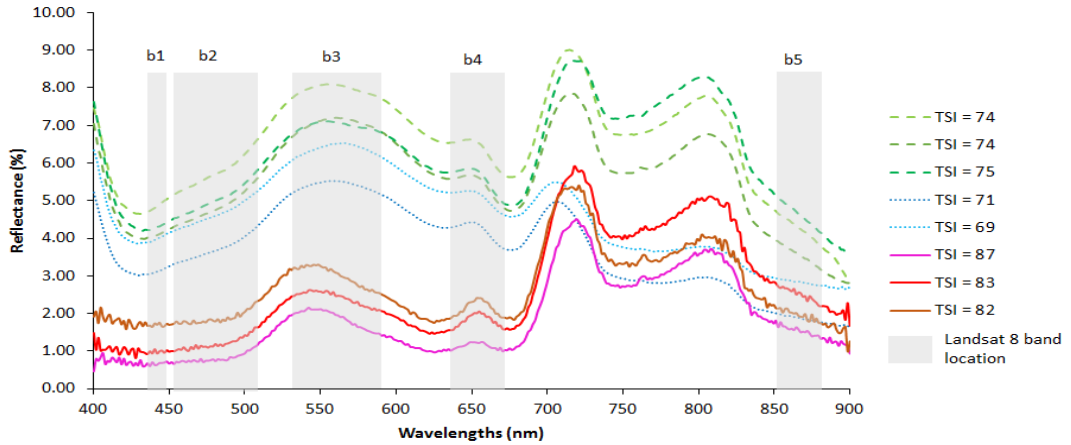


*Figure 2. Reflectance spectra measured at surface water of Lake Linh Dam and corresponding TSI overlaid the Landsat 8 band locations.*

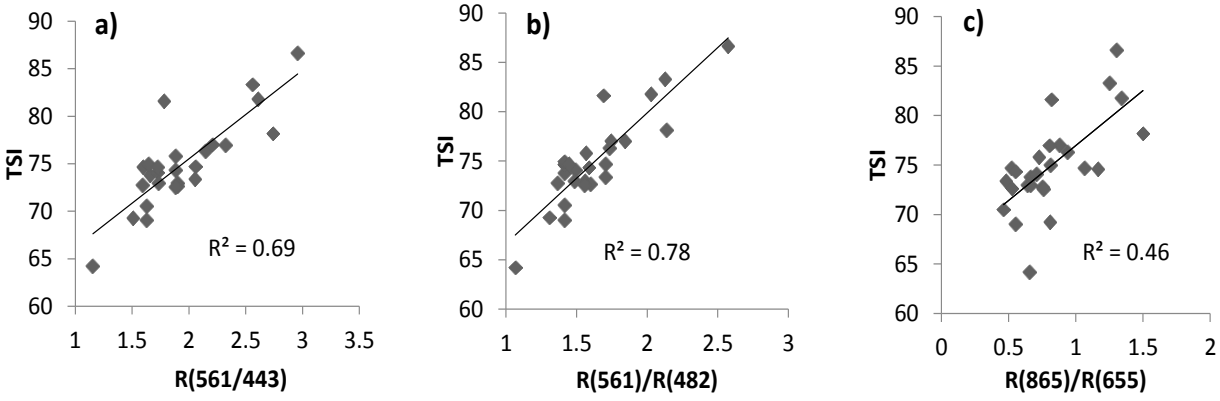


*Figure 3. Relationships between in situ TSI and: a) in-situ R(561)/R(443); b) in-situ R(561)/R(482); c) in-situ R(865)/R(665), confirming the best performance of R(561)/R(482) for estimating the TSI.*

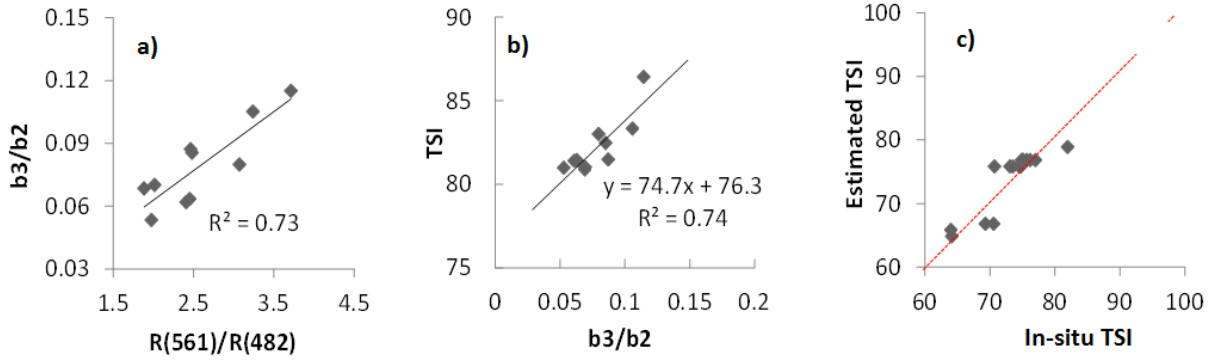


*Figure 4. Relationships between: a) in-situ R(560)/R(483) and ratio of Landsat 8 two-band reflectance ratio of band 3 versus band 2 (b3/b2); b) in-situ TSI and b3/b2; and c) estimated TSI and in-situ TSI.*

Figure 3 shows relationships of TSI with *in-situ* reflectance ratios corresponding to the ratio of bands in blue-green regions, including band 3 versus band 1, R(561)/R(443) (Fig. 3a), band 3 versus band 2, R(561)/R(482) (Fig. 3b) and red-near infrared region corresponding the ratio of band 5 vesus band 4, R(865)/R(655) (Fig. 3c). Accordingly, TSI show the highest correlation to ratio of band 3 (R(561) in green region) vesus band 2 (R(481) in blue region) with R-squared of

0.78 and standard estimated error of TSI value is 2.2 (corresponding to 2-3 % of mean measured TSI).

### *3.2. Estimation TSI of Lake Linh Dam using Landsat 8 imagery*

Figure 4a described relationship of *in-situ* R(561)/R(482) and ratio of band 3 versus band 2 (b3/b2) of Landsat image acquired concurrently on April 1st 2017. Wherein, R(561)/R(482) was related with b3/b2 by a linear function with R-squared = 0.73. This function was then used to transfer relationship of TSI and *in-situ* R(561)/R(482) into relationship of TSI and b3/b2 as in Figure 4b. As result, TSI of Lake Linh Dam can be calculated from Landsat 8 band 3 and band 2 as follows:

$$TSI = 74.7\frac{b3}{b2} + 76.3 \quad (4)$$

where $b3$ and $b2$ is the pixel reflectance retrieved from band 3 and band 2 of Landsat 8, respectively.

Figure 4c shows the validation of Equation 4 when using Landsat 8 images acquired on April 1st 2017 to estimate TSI. Result from comparing of 17 point samples of TSI measured on April 1st and 2nd 2017 confirmed high accuracy of Equation 4 in estimating the lake TSI with the

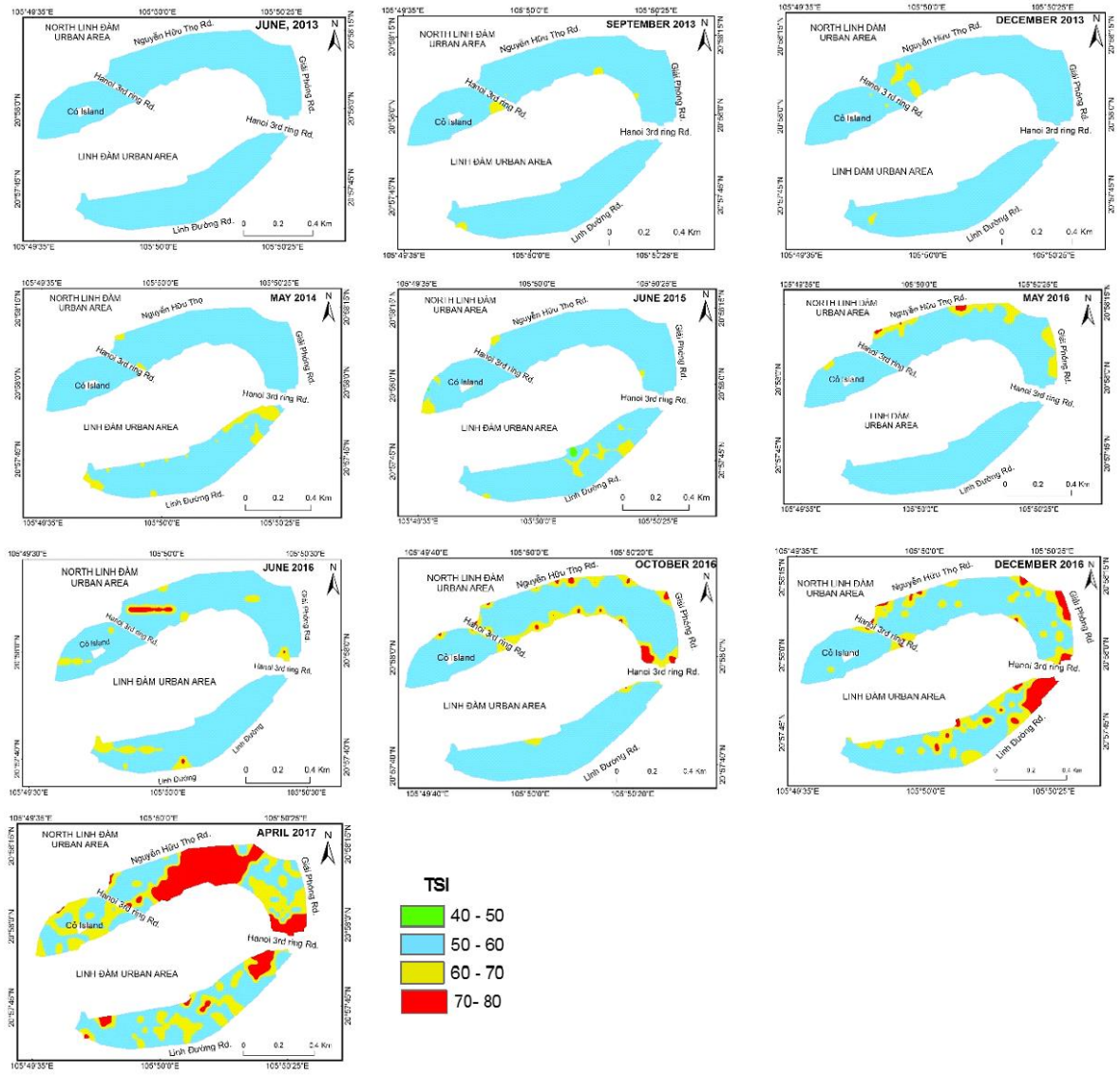


*Figure 5. Time-series maps of estimated TSI for Lake Linh Dam from Landsat 8 images.*

mean standard error of 1.1 corresponding to 1.5 % of mean *in-situ* TSI.

Figure 5 indicated time-series estimations of TSI for Lake Linh Dam using multitemporal Landsat 8 images. Ten images were used to estimate the TSI. Result show that the TSI of Lake Linh Dam has been increased time by time, from 50-60, corresponding to eutrophic level, in 2013 summer to 60-70 in late 2017 Spring. Spatially, high TSI distributed near the lake's shore and decreased in lake's center. Within a year, TSI show an increasing trend from spring to winter. Along with rapid urbanization of surrounding area (the Linh Dam Residential Area), water quality of Lake Linh Dam show a downward trend evidencing by the increase of TSI. Result of this work may be used for further impact assessment of surrounding urbanization on the lake quality in future.

## 4. Conclusion

This work demonstrates a high correlation of water TSI with ratio of Landsat 8 band 3 versus band 2 through the case of Lake Linh Dam. The obtained TSI of Lake Linh Dam estimated from Landsat 8 data has acquired since 2013 show that the lake trophic state has been increased from eutrophic level in 2013 to hypertrophic level in present according to Carlson's lake trophic index. Spatial TSI variation within Lake Linh Dam' waterbody present following a trend that TSI was high in near shoreline waters and decreased towards offshore. The TSI of Lake Linh Dam water has been not conformable to seasonal varation but increased overtime. Result from this work confirmed the capability of Landsat 8 data in monitoring the trophic state of lake water as well as providing scientific database for future monitoring the impact of urbanization on Lake Linh Dam water quality. The methods present in this work can be widely applied for monitoring trophic state in urban areas, particularly for monitoring water quality of hundred lakes in Hanoi frequently toward the city's better environmental management.

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