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RESEARCH ON AN ALGORITHM TO SEPARATE WATER AND LAND BOUNDARIES USING LANDSAT OPTICAL SATELLITE IMAGES FOR RIVER EROSION STUDY

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Abstract

This research aims to introduce an algorithm for separating water and land boundaries using Landsat optical satellite images. The Landsat image is first radiation calibrated and atmospheric calibrated using a FLAASH model. Thresholding algorithm combining with image ratio was then applied to separate boundaries between water and land. The results of separating water and land boundaries from two Landsat-5 and Landsat-8 images of the confluence of Thao river, Da river and Lo river taken in 2008 and 2017 show that the algorithm has effectively separated water and land boundaries of this region. This research enables an important method to identify changes and to monitor landslide erosion in Vietnam river basins.

Keywords: LANDSAT image; Image aspect ratio algorithm; Water and land boundary; Optical satellite image; The confluence of Thao, Da and Lo river.

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1. Introduction

River erosion has occurred frequently in many river basins in recent years, causing severe damages to both the life and property of the State and the people, instabilities of residential area and riverside infrastructure. Especially in estuary areas, they are often affected by modern tectonic movements (lifting and lowering structures, faults), sea level rise, rainfall change, river flows and human activities such as building hydropower dams, irrigation, aquaculture, mangrove planting. Thus, the monitoring of river bank erosion is a particularly important task. One of the methods commonly used by recent studies is through the monitoring of riverbank fluctuations by traditional measurement methods. The limitations of this method are its inapplicability to apply in large ranges, high costs and dependent on weather conditions. Therefore, the popular method in recent decades is stereoscopic measurement with GPS (Global Positioning System) tracking points. However, the biggest drawback of this approach is difficult to conduct multiple monitoring in a large scale. In recent years, thanks to the strong development of universal technologies, Remote sensing “RS” has had outstanding advantages of providing a series of visual, objective, extensive and detailed images of the Earth’s surface over a long period of time. It has been widely used in environmental monitoring, especially natural disasters. In particular, with the coverage of large remote sensing images, the information extracted from the riverbank variation through the demarcation of the water and ground boundaries is consistent, helping to monitor river bank erosions effectively. In Vietnam, the application of RS and GIS to evaluate changes of riversides has been implemented by using medium resolution satellite imagery such as Landsat TM, ETM+, OLI, high resolution such as SPOT and VNREDSat and ultra high resolution such as QuickBird and IKONOS at many river mouths such as Tra Ly, Ba Lat, Van Uc, and Day Gate [4], Loc An [5], lower sections of Ba river [6] and Thu Bon river [7]. Besides, there are some typical studies applying Remote Sensing to study on landslides in the Nile basin (Egypt)[8] and the Yellow River (China) [9].

The commonly used methods are image classification and water, soil separation indicators such as NDWI MNDWI, NDMI, WRI, NDVI, and AWEI [10]. Though thresholding algorithm is one of the simple and quite effective methods, its disadvantage is at transition zones between land and water, where the result would be in confusion. If combined with image aspect ratio algorithm, this disadvantage can be overcome.

2. Study area

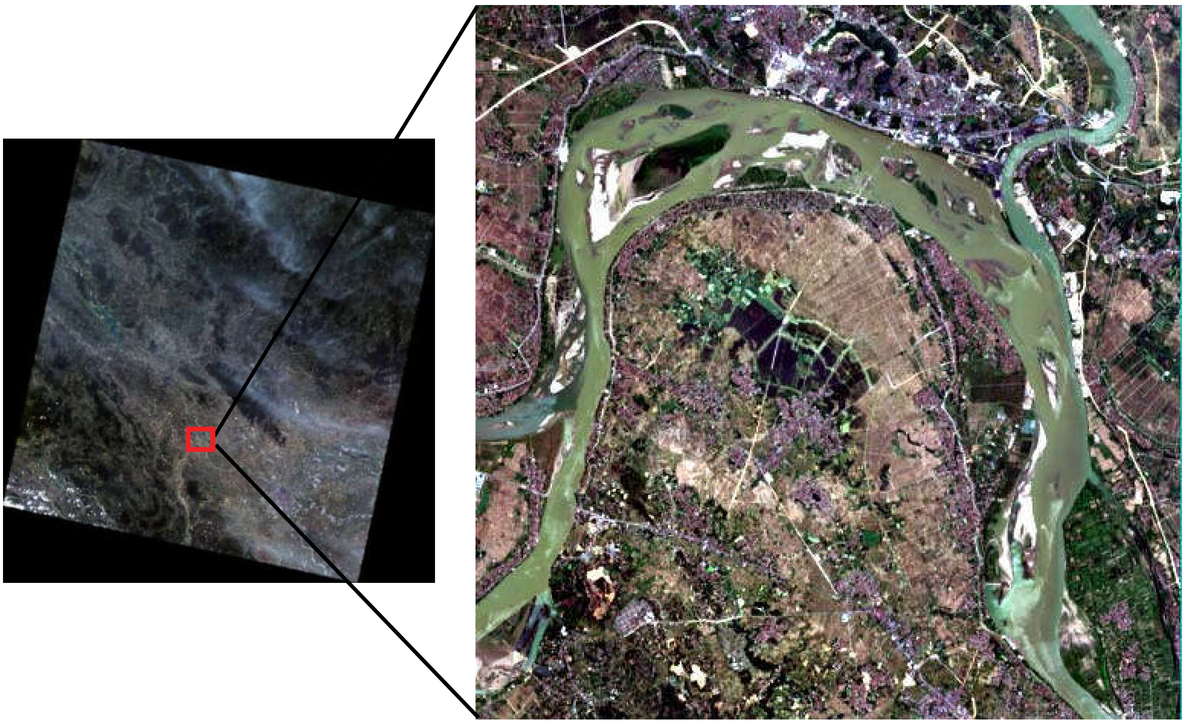


Figure 1: Landsat 8 OLI image (left) and research area image (right).

The confluence area of The Thao, Da and Lo river stretches over 30 km in the districts of Lam Thao, Tam Nong, Viet Tri city (Phu Tho province) and Ba Vi district (Ha Noi). These regions are crowded with residents, including Viet Tri - the center of Phu Tho province. Erosion at riverside frequently occurs at both left and right banks and always has complex happening [11]. The main reason causing erosion is due to endogenous factors (geology, tectonic structure and activity of tectonic faults). Exogenous factors such as river bed morphology, hydrological characteristics, river bank soil structure and human activities also lead to increasing erosion. In addition, human activities such as regulating the water of Hoa Binh reservoir and the embankment system also contribute to the complexity of the erosion and depositional erosion, which sometimes changes the law of river bed development at the confluence of Thao, Da and Lo [11].

Most recently, landslides have been observed in two areas of the confluence with the length of nearly 400 m; The widest point is about 30 m. The landslide also made 8,000 m^2 of farmers flowing into the river. Therefore, this study aims to extract boundaries between water and land for landslide monitoring in the Thao, Da and Lo river confluences for the period 2010 - 2017 from LANDSAT satellite imagery. The main sources are from Landsat - 5 TM and 8 OLI satellite images collected from the US Geological Survey (USGS) website. Two 30 m spatial resolution images, Path / Row 127/45, were collected on July 29, 2008 and June 4, 2017 (Fig. 1). Satellite imagery was corrected for L1TP level and was standardized with WGS 1984 UTM, Zone 48 North.

3. Research methods

3.1. Sensor calibration

Sensor calibration is the process of converting integer values to the actual value of the electromagnetic radiation received by the sensor. Correction of the error caused by the sensor is done by the ENVI software via formula (1) for the LANDSAT 5 TM image and formula (2) for the LANDSAT 8 OLI image [12, 13]:

$$L_\lambda = \frac{Lmax_\lambda - Lmin_\lambda}{Q_{calmax} - Q_{calmin}}\left(Q_{cal} - Q_{calmin}\right) + Lmin \quad (1)$$

where is the spectral radiance [W/(m^2.sr.µm)]; Q_{cal} is the quantized calibrated pixel value, Q_{calmin} is the minimum quantized calibrated pixel value (equal to 1), Q_{calmax} is the maximum quantized calibrated pixel value (equal to 255). *LMIN* and *LMAX* is the spectral at-sensor radiance that is scaled to Q_{calmin} ($W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$) and to Q_{calmax} ($W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$) respectively [14].

$$L_\lambda = M_L.Q_{cal} + A_L \quad (2)$$

M_L, A_L, are the radiance multiplicative scaling factor (taken from the metadata) and the radiance additive scaling factor (taken from the metadata) respectively; Q_{cal} = the L1 pixel value in DN

3.2. Calibration of the atmosphere effect

When receiving satellite images, Electromagnetic radiation is degraded by scattering of light by aerosols (such as sand, dust, smoke, and CO2, etc.) and absorbed by water vapor during atmospheric transmission [15]. In this study, the FLAASH model (Fast Line-of-Sight Atmospheric Analysis of Hypercubes) is used to correct the atmospheric effects on the reflector channels of the Landsat - 5 TM and 8 OLI satellite images. In the FLAASH model, the value of electromagnetic radiation at the top of the atmosphere, L *, is determined by equation (3) [13, 15]:

$$\mathrm{L}^* = \left(\frac{A\rho}{1-\rho_e S}\right) + \left(\frac{B\rho_e}{1-\rho_e S}\right) + \mathrm{L}^*_\mathrm{a} \quad (3)$$

Where: ρ is the pixel surface reflectance; ρ_e is an average surface reflectance for the pixel and a surrounding region; S is the spherical albedo of the atmosphere; L_a is the radiance back scattered by the atmosphere; A and B are coefficients that depend on atmospheric and geometric conditions, not on the surface.

3.3. The algorithm for separating water and soil boundary

$$R_{G/S} = \frac{R_{Green}}{R_{SWIR1}} \qquad (4)$$

If R_ (CS)> 1, the pixel's attribute is set to water; otherwise, if R_ (G / S) <1, the pixel attribute is set to earth (or not water).

$$R_{G/N} = \frac{R_{Green}}{R_{NIR}} \qquad (5)$$

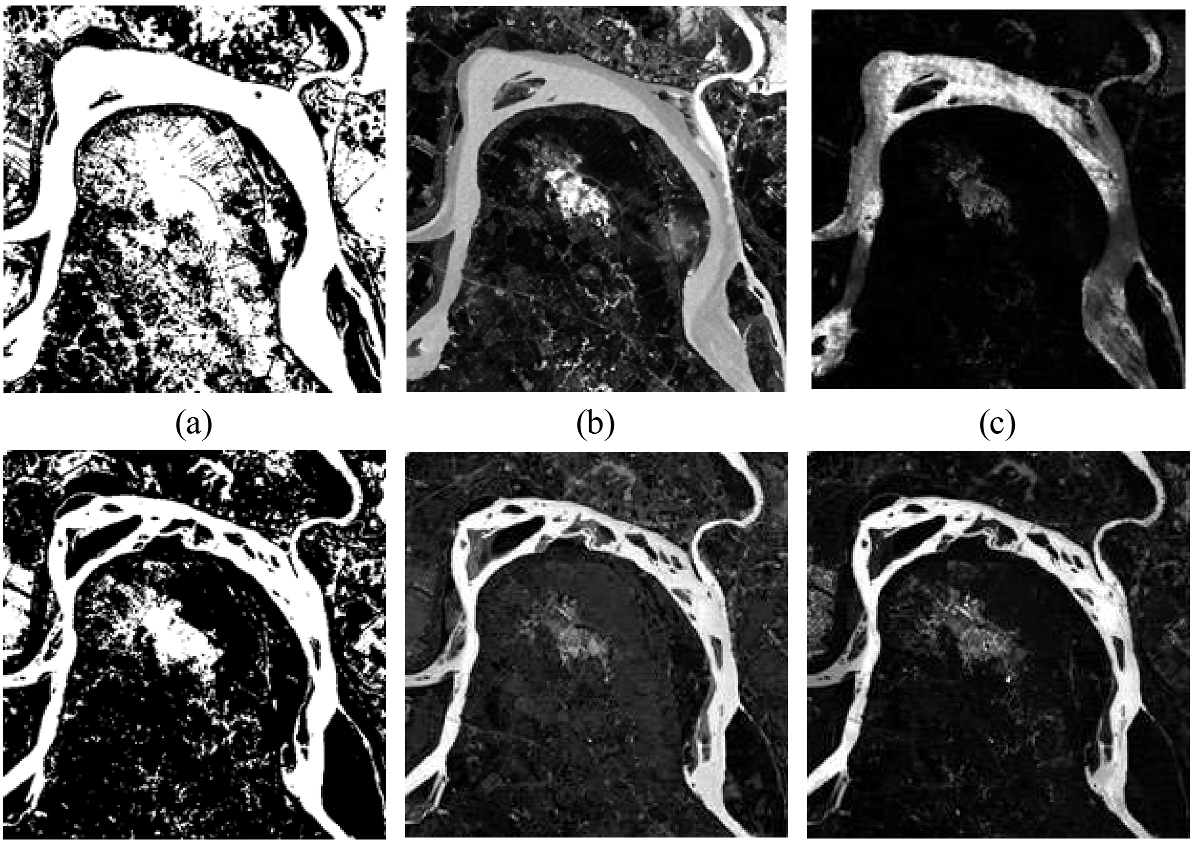
If , the pixel is defined as water. If, the pixel is considered as land or not water. Thresholding image and two ratio images will be combined to produce a boundary image. The boundary image will be processed to remove unnecessary noises. After that, vector method was applied to identify the water and land boundary.

4. Result and discussion

The result with LANDSAT image collected on 29th July 2008 and 4th June 2017 was illustrated in Fig. 2-a and 2-d. In those figures, water is valued at 1 (white), land is valued 0 (black). In the green/ infrared wave (Fig. 2-b and 2-e) and green/low- infrared wave (Fig. 2c and 2-f), the color white indicates surface water, grey and black indicate soil. The binary image boundary is derived from the subdivision image and shown in Fig. 2. After noise and vectorization, the water and land boundaries are shown in Fig. 4.

The results of separating the water and land boundaries in two periods (29th July, 2008) and (4th June 2017) showed that the shoreline was quite fluctuated. The large fluctuations occured in Tan Duc, Ben Got, Vinh Loi, Cao Xa commune of Viet Tri city (Phu Tho) and Phu Cuong, Phu Chau commune of Ba Vi district (Hanoi). Compared with the shoreline in 2010, the accretion areas are located in Tan Duc (Viet Tri); Vinh Loi (Lam Thao); Phu Chau (Ba Vi). The erosion is reported in Phu Cuong, Phu Chau (Ba Vi), Ben Got (Viet Tri city); Cao Xa, Vinh Loi (Lam Thao) and Minh Chau (Vinh Tuong). The stable coastal areas are observed in Tien Cat, Tho Son (Viet Tri); Cao Dai, Bach Hac (Vinh Tuong); Co Do, Phong Van and Thai Hoa (Ba Vi). It is clear to be seen that while the coastline in Ba Vi area is stable, there were some changes of the coastline (accretion or erosion) in Tan Duc, Cao Xa, Ben Got (Viet Tri).

The results of separating the shoreline in two periods (29th July, 2008) and (4th June 217) showed that the shoreline was quite fluctuated. The large fluctuation occured in Vinh Loi, Cao Xa, Tan Duc and Ben Got commune of Viet Tri city (Phu Tho) and Phu Cuong, Phu Chau commune of Ba Vi district (Hanoi). It is clear to be seen that there is no change in the shoreline at the confluence of Ba Vi district (Hanoi) including Thai Hoa, Phong Van, Co Do, Tan Hong, Chau Son, Phu Thong, Tien Cat, Tho Son (Viet Tri city, Phu Tho); Cao Dai (Vinh Tuong district, Vinh Phuc). As can be seen, the shoreline changes in the left bank of Tan Duc (Ba Vi), Minh Nong, Ben Got, Vinh Loc, Cao Xa (Lam Thao district). Due to the conduction changes, the river bank erosion appeared and the the accretion is reported in these areas. Endogenous factors (geology, tectonic structure and techtonic fault) are the main causes of shoreline erosion. Exogenous factors such as river bed morphology, hydrological characteristics, river bank soil structure and human activities play the important roles in promoting this process. Due to the geological features and tectonic structure, it is observed a Northward horizontal erosion of river bed and this is true for river bed development at river curves. Human activities (water regulation of Hoa Binh lake, embankment system) not only contribute to the serious issues of erosion and sediment but also change the trend of the riverbank development.



(a) (b) (c)

(d) (e) (f)

Figure 2: NIR Image (figure a and d), Blue/NIR image (figure b and e) and Blue/SWIR1 (figure c and f) from Landsat - 5 TM image (up) and Landsat - 8 OLI (down).

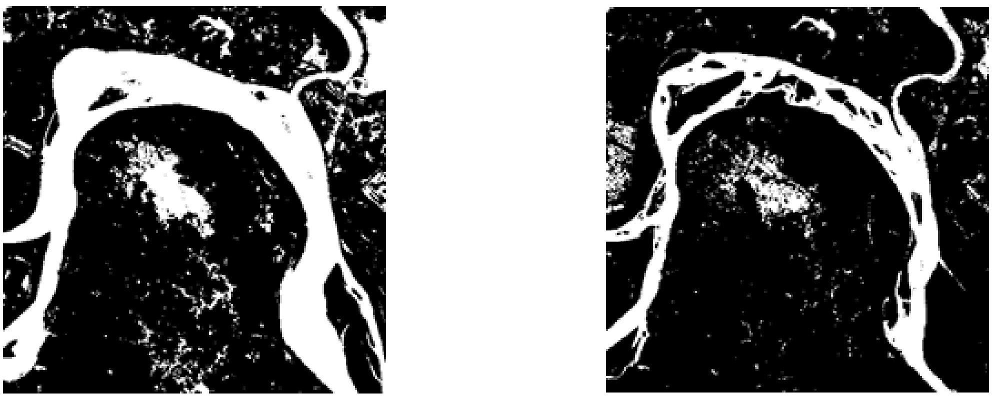


Figure 3: Binary Boundary Image from LANDSAT - 5 TM (left) and LANDSAT - 8 OLI (right)

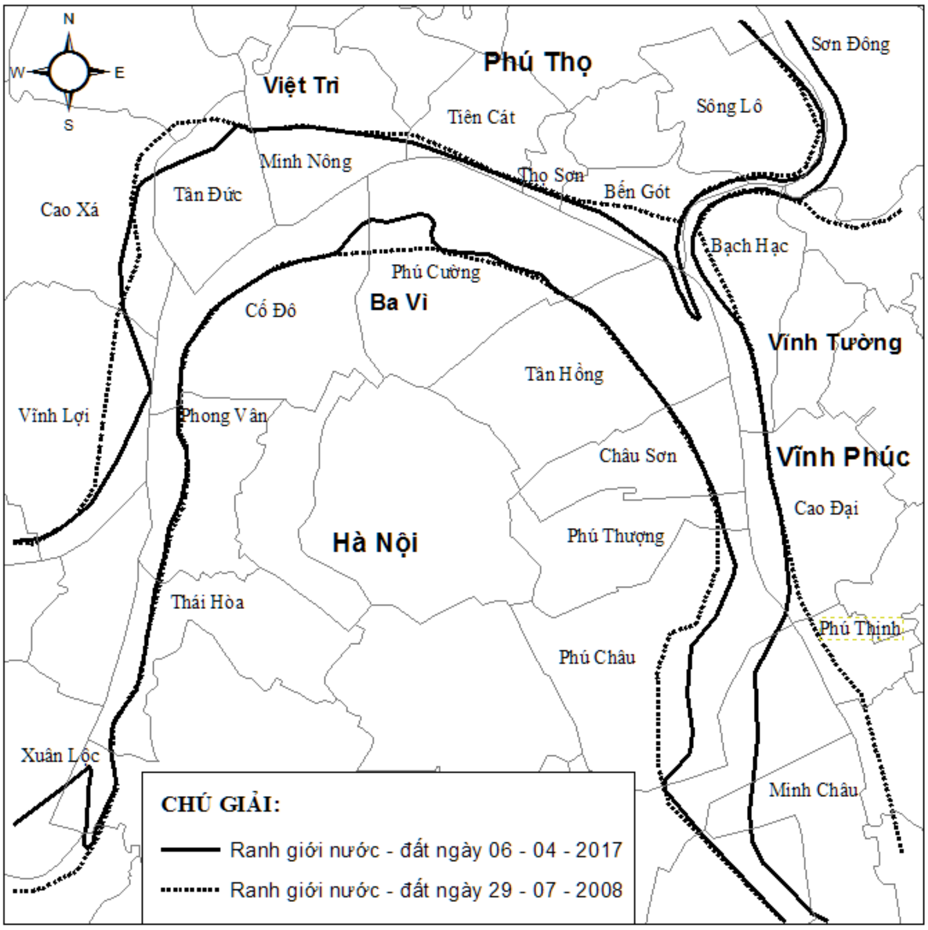


Figure 4: Soil and Water Boundary in the confluence Thao, Da and Lo River on 29th July 2008 and 4th June 2017

5. Conclusion

The paper shows an algorithm for separating water and soil boundary from LANDSAT optical satellite imagery. Due to the radiation error, the LANDSAT image was calibrated atmospheric. The theoretical basis was introduced and applied to separate the water and soil boundary at the confluence of Thao, Da and Lo river. The experiment of land and water boundary separation was collected from 2008 to 2017. It was proved the effective algorithm. However, there were some issues in this study. First, the extraction of shoreline from satellite imagery requires a lot of satellite imagery in the similar time (or similar season) and cannot be combined with tide and other conditions to reduce the impact of errors during shoreline identification. The limitation of this study will be addressed in the coming studies so that the separation of water and land boundary is more accurate and reliable and monitoring the process of erosion and sediment in Vietnam's river basin is more effective.

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