VIỆN HÀN LÂM KHOA HỌC VÀ CÔNG NGHỆ VIỆT NAM
VIETNAM ACADEMY OF SCIENCE AND TECHNOLOGY

ISSN 1859-3097

Tạp chí KHOA HỌC VÀ CÔNG NGHỆ BIỂN

JOURNAL OF MARINE SCIENCE AND TECHNOLOGY

4 (T.18)
2018

HÀ NỘI

JOURNAL OF MARINE SCIENCE AND TECHNOLOGY

Vol. 18, No. 4 - September 2018

CONTENTS

Journal of Marine Science and Technology; Vol. 18, No. 4; 2018: 339–349
DOI: 10.15625/1859-3097/18/4/10271
http://www.vjs.ac.vn/index.php/jmst

INTERPRETATION OF WATER INDICES FOR SHORELINE EXTRACTION FROM LANDSAT 8 OLI DATA ON THE SOUTHWEST COAST OF VIETNAM

Tran Anh Tuan[1,*], Le Dinh Nam[1], Nguyen Thi Anh Nguyet[1], Pham Viet Hong[1], Nguyen Thi Ai Ngan[2], Vu Le Phuong[1]

[1]*Institute of Marine Geology and Geophysics, VAST, Vietnam*
[2]*Suoi Hai Prison, General Department No. 8, Vietnam Ministry of Public Security, Vietnam*
[*]E-mail: tatuan@imgg.vast.vn

Received: 26-6-2017; accepted: 10-8-2017

Abstract. The paper presents results of analysis of water indices using remote sensing data to extract an instantaneous shoreline at the time of image acquisition on the southwest coast of Vietnam. The water indices as NDWI (Normalized Difference Water Index), MNDWI (Modified Normalized Difference Water Index), and AWEI (Automated Water Extraction Index) were calculated from Landsat 8 OLI imagery. Then, an extracted distribution histogram of water indices' values in the study area was used to separate the land from the sea. The position having abnormal frequency of pixels on the histogram is the threshold value to determine the boundary of land and water, and it is considered the shoreline. The study showed the threshold values of NDWI, MNDWI and AWEI which were defined at 0.12, 0.17 and 0.18 respectively. The precision of shoreline extraction from each respective water index was verified by field survey data using Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) methods. The verified results showed that MAE and MSE of the shorelines extracted from all three water indices were lower than an allowed limit of 30 m (equivalent to spatial resolution of the Landsat 8 image). However, the shoreline extracted from AWEI had the highest accuracy and it was considered the most appropriate shoreline at the acquisition time of image.

Keywords: Water indices, shoreline, remote sensing, Landsat 8 OLI, Southwest of Vietnam.

INTRODUCTION

The coastal zone is a mixed region under both terrestrial and marine regimes, in which anthropogenic activities has drastically modified the local physical and environmental conditions to serve his own resource demand and economic growth. For the same reason, in the recent years, the geological and environmental conditions of the Southwest coast of Vietnam have undergone numerous transformation processes, especially on the coastal plain. On the supratidal plain, the pristine topology encountered positive transformations in order to serve socio-economical development objectives, which mostly focused on cultivation, fish farming, reclamation and urbanization. On the coastal zone, the mangrove extended in vast, especially in the territory of Ca Mau province. According to former surveillance results, literacy collection and historical archives on the changes of the coastal zone in the study area, the shoreline shifting was remarkable, of which coastal erosion had caused severe loss to the economical development and ecological-environmental conditions in the area, e.g. the eroded coast of Kien Giang province accounted for about half the total coastline length [1]. Another example was the Kim Qui Border Guard Station on the estuary of Vam Kim river, where the shoreline has been temporarily stabilized by embankments. In the last 20 years (1997–2017), the station had been relocated three times due to coastal erosion, with the loss of an area with width up to 600 m. In other locations, such as the Cape of Ranh on the south bank of Cai Lon river and Vam Ray river in Hon Dat district (Kien Giang), the shoreline had retreated inland up to 200 m from 2001 to 2008 [2]. Former studies on shoreline shifting in the period of 1996–2006 divided the area into 5 regions with distinctive transformation grade, of which the shoreline sections from Van Khanh commune (An Minh district) to Cai Doi Vam county (Phu Tan district) were the most eroded at mean annual rates from 2 m/yr (minimum) to 24 m/yr (maximum); meanwhile the shoreline sections from Bay Hap river mouth to Dat Mui commune predominantly experienced aggradation at high rates, ranging from 35 m/yr to 80 m/yr - also the most drastic change in the study area [3].

On the coastal zone, the use of remote sensing time series data for monitoring the conditions and shoreline shifting could be consider the extremely effective method with the significant accuracy. Shoreline extraction can be performed using various approaches, such as single-band thresholding, band ratio or water indices. The single-band thresholding approach is based on the reflectance distinctions of land and water objects [4, 5]. The energy of near infrared (NIR) and infrared (IR) wavelength is strongly absorbed by water, thus the reflectance of water bodies is significantly lower than that of other land cover types. Therefore, the NIR and IR bands are usually applied for the purpose of shoreline delineation. The band ratio approach is also a frequent method for the same intention by calculating the ratio value of band 4/band 2 and band 5/band 2 of Landsat 7 images: The boundary between water bodies and subaerial environments is as 1, while the pixel values are designated for water bodies and subaerial environments as over 1 and less than 1, respectively [6]. In order to improve the performance accuracy in distinctive classification of water and other land covers, various water index approaches had been nominated. McFeeters, S. K., (1996) [7] introduced the NDWI - which later became the most commonly used method for delineating boundary between water and land. Xu, H., (2006) [8] suggested a renovated approach called Modified Normalized Difference Water Index (MNDWI) by the replacement of the Short-wave infrared band (SWIR) instead of NIR band in the original formula of McFeeters. Feyisa, G. L. et al., (2014) [9] provided a new method using stabilised threshold value and accuracy improvement in dark and shadow surfaces where other approaches are regularly misinterpretated.

This study is using the data of Landsat 8-OLI imagery to calculate three water indices, including NDWI, MNDWI and AWEI, then investigate the frequency distribution chart of their values to determine threshold values and extract spontaneous shoreline at the image acquisition time on the Southwest coast of Vietnam. Field trip for groundtruth data collection for later accuracy assessment was taken in the study area to evaluate the performance of the three water index approaches and specify exact location of shoreline at the image acquisition time.

DATA USED AND METHODOLOGY

Data used. The selected study area is within the coastal zone of Ca Mau province and Kien Giang province of Vietnam, with estimated length of approximately 600 km, covered by large extent of mangrove and small island group in the limitation from 104°25’E to 105°10’E, 08°30’N to 10°25’N (fig. 1). Database and literature collection for the study include:

Survey data collection includes 21 groundtruthing locations on the coastline of study area during field trips taken in March and April, 2017, which are in the framework of the project code VT-UD.01/16–20, belonging to the Vietnam Aerospace Science and Technology Program (2016–2020). A map of groundtruthing locations is described as in fig. 1 below. Distance between actual shoreline location visited during field trip and corresponding location derived from satellite images is used to establish and evaluate the error value of calculated results.

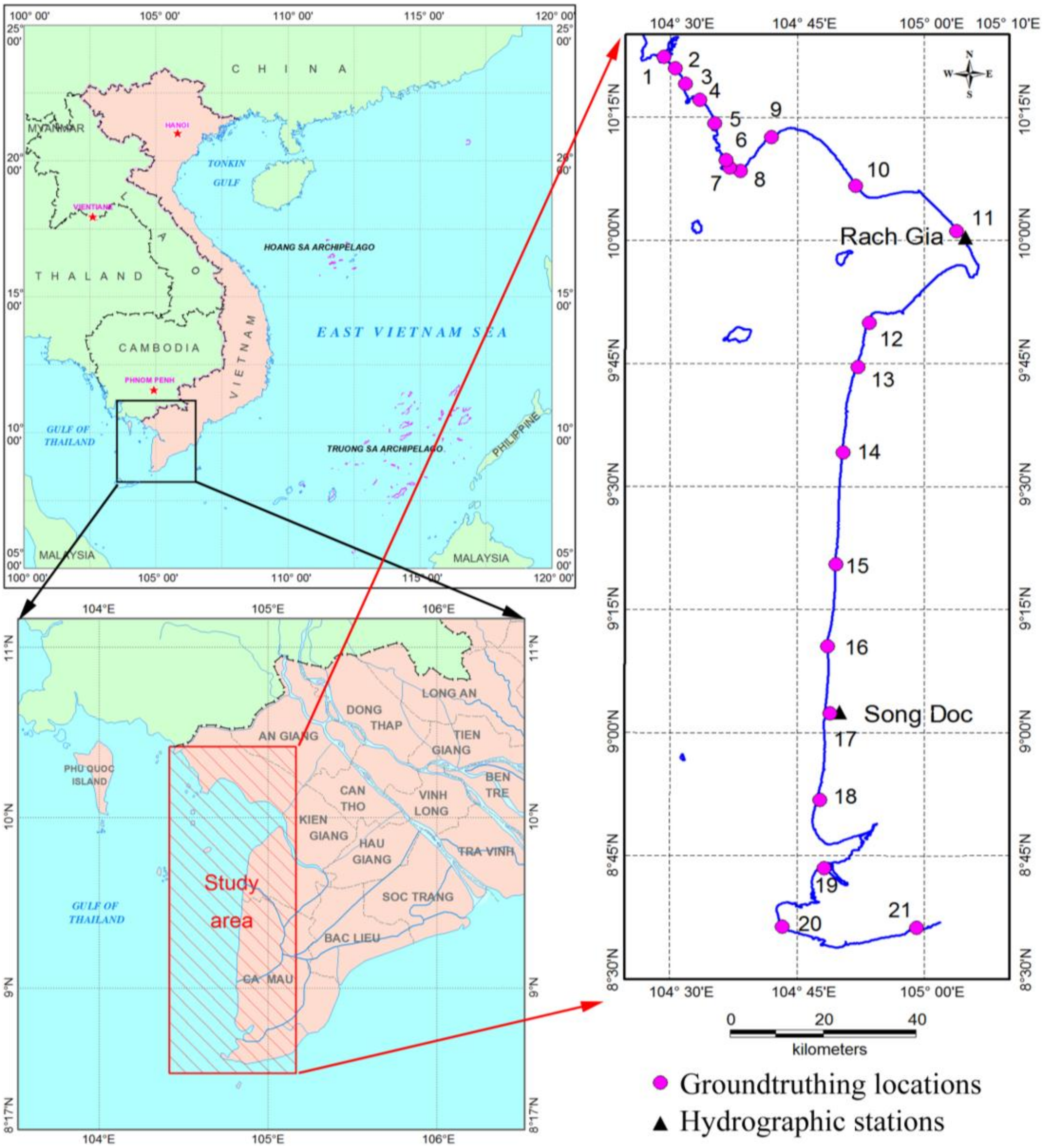

Fig. 1. Study area domain and groundtruthing positions

The Landsat 8 satellite is equipped with Operational Land Image/Thermal Infrared Sensor (OLI/TIR) to improve image signal quality over older sensor generations. Landsat 8 OLI/TIR scenes are distributed complimentarily by the United States Geological Survey (USGS) via Global Visualization Viewer (GLOVIS) portal (http://earthexplorer.usgs.gov/). In this study, the selected scenes had the acquisition time of February 19th, 2016 with cloud coverage less than 10%. The scenes were pre-processed at L1T grade with geo-coordinates of UTM zone 48 North, WGS-84. Descriptions of the scenes are presented in table 1 and fig. 2.

Table 1. Description of Landsat 8 scenes and bands used in the study

Scene	Acquisition time	Acquisition date	Sensor	Designated band and corresponding wavelengths (μm)	Tide height at the acquisition time (cm)
126-53	10:20:18	19/02/2016	OLI	Band 3 (Green): 0.525–0.600 Band 4 (Red): 0.630–0.680 Band 5 (NIR): 0.845–0.885 Band 6 (SWIR1): 1.560–1.660 Band 7 (SWIR2): 2.100–2.300	0
126-54	10:20:43				-19

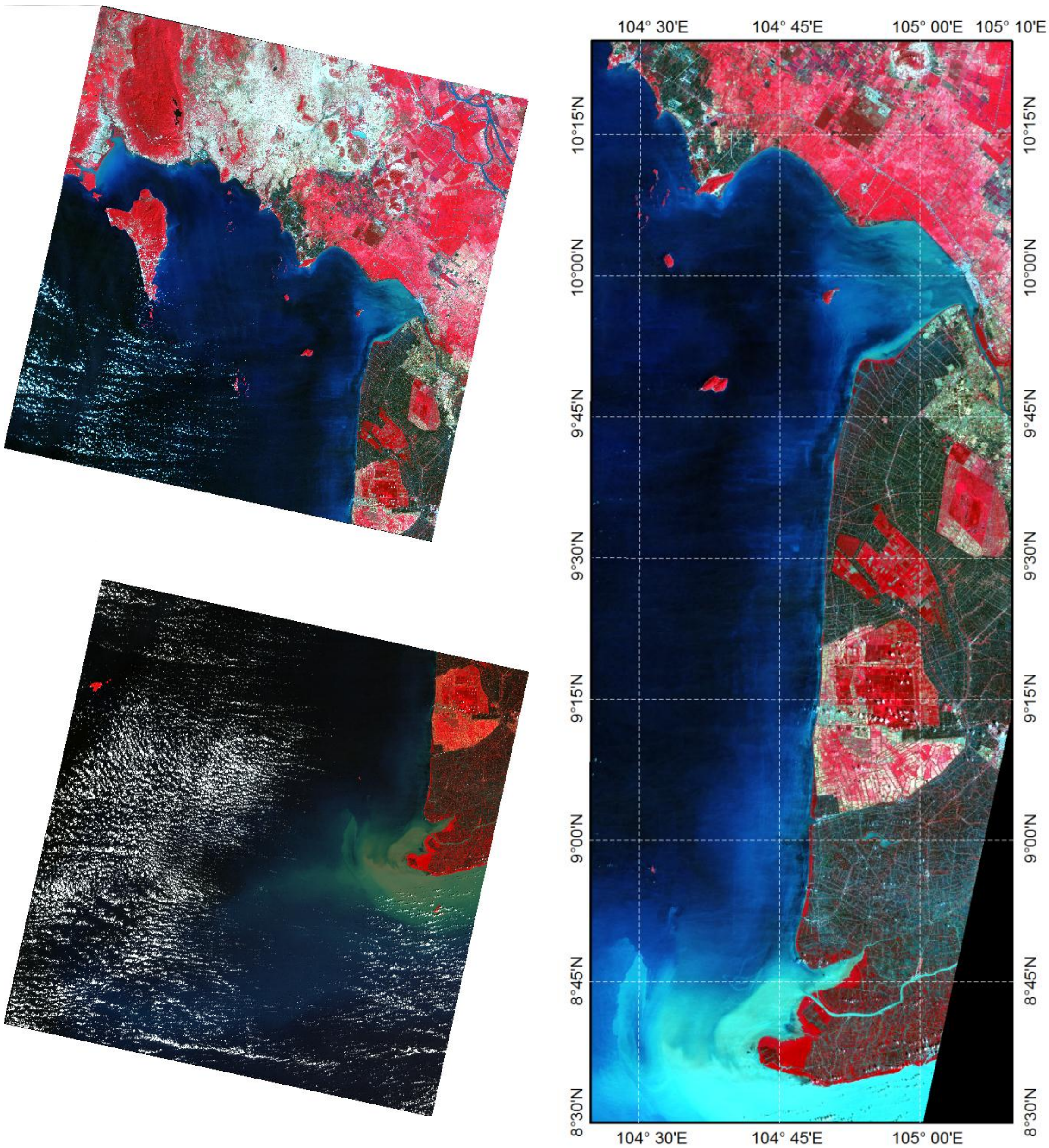

Fig. 2. False composite of Landsat-8 scenes using band 5, 4, 3 (left) and pre-processed scene mosaic of the study area (right)

Tide height of February 19th, 2016 at the hydrographic stations of Rach Gia for the 126-53 scene; and Song Doc for the scene 126-54 to estimate tidal influence on the spontaneous shoreline is derived from satellite data. Corresponding tidal levels in the two stations at the scene acquisition time are 0 cm and -19 cm, respectively (table 2).

Table 2. Tide height at February 19th, 2016 in the hydrographic stations of Rach Gia and Song Doc

Station	Station position		Tide height (cm)																							
	Longitude	Latitude	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*
Rach Gia	105.05	10.00	45	44	38	29	18	6	-4	-10	-12	-11	-6	**0**	1	-2	-10	-17	-23	-24	-21	-12	-2	10	21	32
Song Doc	104.50	9.02	38	35	28	19	9	-1	-9	-16	-20	-21	-20	**-19**	-17	-14	-11	-7	-5	-4	-3	0	6	15	24	33

Practical condition of mangrove is classified from 126-54 scene with same acquisition time (fig. 3b). On the mangrove infested coast, the actual shoreline position was covered, thus it was impossible to locate the exact physical shoreline (fig. 3a). In the study, the seaward boundary of mangrove could be regarded as the designated shoreline.

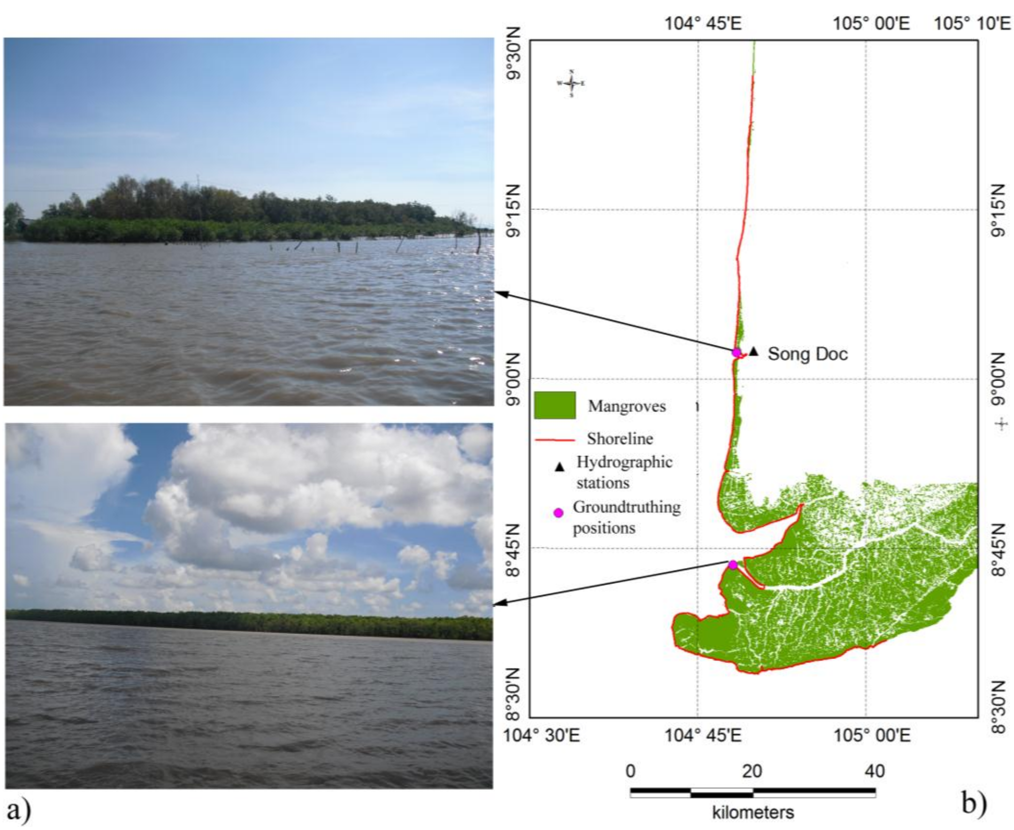

Fig. 3. a) Shoreline with mangrove cover as seen on the actual condition,
b) Mangrove distribution map derived from scene 126-54

Methodology

Pre-processing methods. In applied remote sensing, pre-processing is a necessary preparation for any further thematic analysis. The pre-processing procedure includes reflectance correction, atmosphere correction, clip and mosaic scenes. Firstly, digital number values in original, untouched scenes are converted into corresponding radiance values at sensor. Then FLAASH (ENVI's Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) atmospheric correction tool is applied to convert radiance at sensor into radiance at top of atmosphere (TOA). Finally, TOA values are converted back to surficial radiance. Pre-processed scenes are mosaicked and clipped as confined study area (fig. 2).

Water index approaches. Water index approach as presented by McFeeters, S. K., (1996) [7].

$$NDWI = \frac{\rho_{Green} - \rho_{NIR}}{\rho_{Green} + \rho_{NIR}} \quad (1)$$

Where: ρ_{Green} is the radiance of green band; ρ_{NIR} is the radiance of NIR band.

The value of NDWI ranges from -1 to 1, with 0 being used as threshold value, hence water bodies are where NDWI > 0, while other land cover types are where NDWI < 0.

Water index approach as presented by Xu, H., (2006) [8].

$$MNDWI = \frac{\rho_{Green} - \rho_{SWIR}}{\rho_{Green} + \rho_{SWIR}} \quad (2)$$

Where: ρ_{Green} is the radiance of green band; ρ_{SWIR} is the radiance of SWIR band.

The threshold value to distinguish boundary between land and water is when MNDWI = 0, similar to NDWI. Water bodies are designated where MNDWI > 0, and other land cover types are where MNDWI < 0.

Water index approach as presented by Feyisa, G. L. et al., (2014) [9].

$$AWEI = 4 \times \left(\rho_{band2} - \rho_{band5}\right) - \left(0.25 \times \rho_{band4} + 2.75 \times \rho_{band7}\right) \quad (3)$$

Where: ρ is radiance value of Landsat TM bands. For Landsat 8-OLI scenes, corresponding bands in the formula are bands 3, 6, 5, 7. Threshold value for identifying water - land boundary is 0, in which water bodies are where AWEI > 0, and other land cover types are where AWEI < 0.

Validation of shoreline extraction. The study uses the error evaluation to assess the accuracy of shoreline extraction results compared to practical shoreline position located during field survey. There are 2 error evaluation methods which were applied as follows:

Mean absolute error: Is the absolute arithmetic mean of practical error elements, described by the formula [10]:

$$\theta = \pm \frac{|\Delta_1| + |\Delta_2| + |\Delta_3| + ... + |\Delta_{n-1}| + |\Delta_n|}{n} \quad (4)$$

Where: θ is the mean absolute error; Δ_n is the practical value of each error element; n is the number of error element.

Root mean square error: Is the root of arithmetic mean of squared practical error elements, described by the formula [10]:

$$m = \pm \sqrt{\frac{|\Delta_1^2| + |\Delta_2^2| + |\Delta_3^2| + ... + |\Delta_{n-1}^2| + |\Delta_n^2|}{n}} \quad (5)$$

Where: m is the root mean square error; Δ_n is the practical value of each error element; n is the number of error element.

RESULTS AND DISCUSSION

Calculation of water indices and automated shoreline extraction. The three water indices of the study area, including NDWI, MNDWI and AWEI, were calculated individually following the (1), (2), (3) formulas. Value distribution chart of those indices showed the boundary between water and land with the considerable precision. The NDWI value ranges from -0.5 to 0.25, of which the -0.5 to 0.12 spectrum has the pixel frequency lower than 100,000, and after 0.12 the pixel frequency extremely increases up to 900,000. Hence, the abrupt point of 0.12 is assigned as a threshold value, where pixel having a value of NDWI < 0.12 is defined as land cover types, otherwise if NDWI > 0.12 it is defined as water bodies. Shoreline is distinguished as where NDWI = 0.12 (fig. 4).

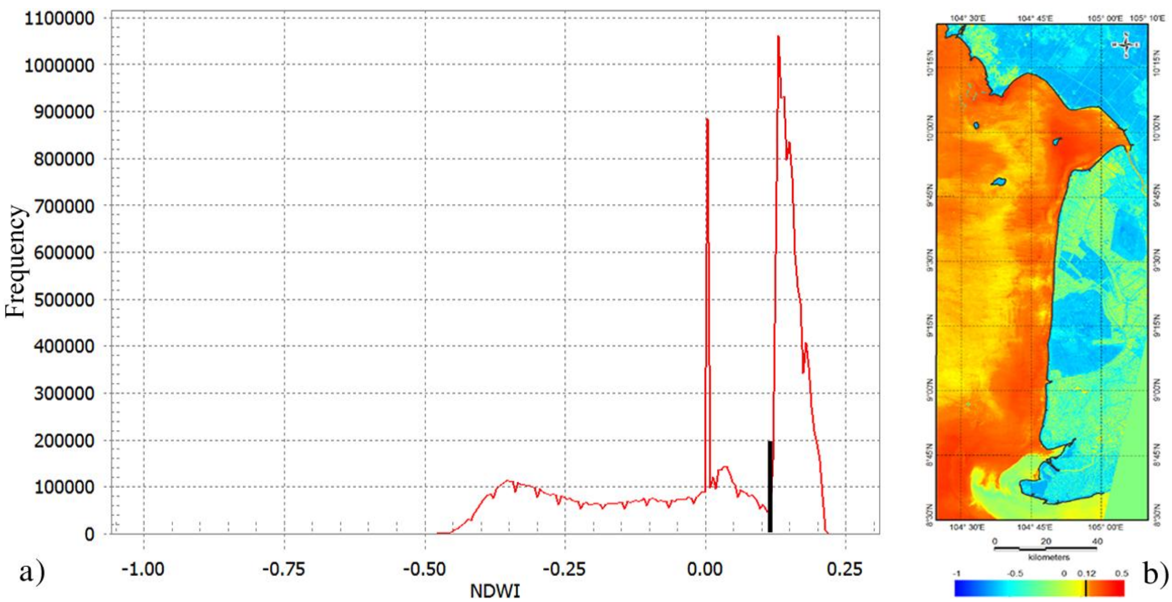

Fig. 4. a) NDWI value distribution chart, b) Shoreline extraction from NDWI

Similar to NDWI, the value of 0.17 is assigned as the threshold value for MNDWI and 0.18 as the threshold value for AWEI. The pixels having value less than threshold value are defined as land, while pixels having the value greater than threshold value are defined as water (fig. 5–6). The threshold values are also assigned for the extracted shoreline sections, as shown in fig. 5b and fig. 6b.

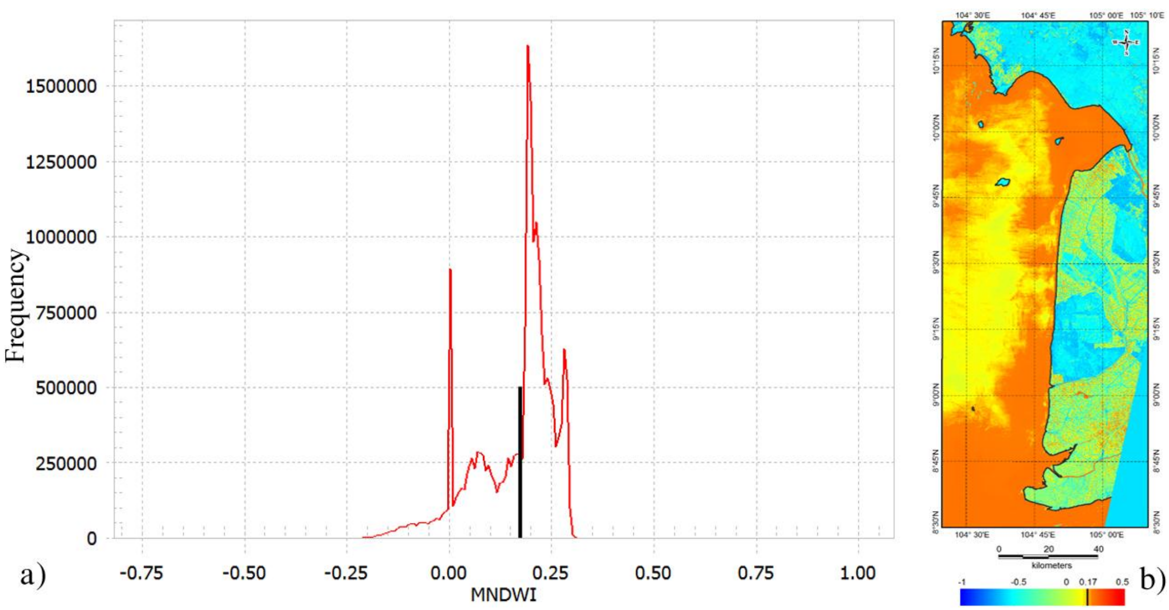

Fig. 5. a) MNDWI value distribution chart, b) Shoreline extraction from MNDWI

In the water index value distribution charts, the black segment marks the abrupt points where the pixel frequency suddenly changes and exposes the threshold value between land

and water on the water index map. The maximal value at 0 point on the charts shows the no-data area which lies on the bottom right corner of the study area.

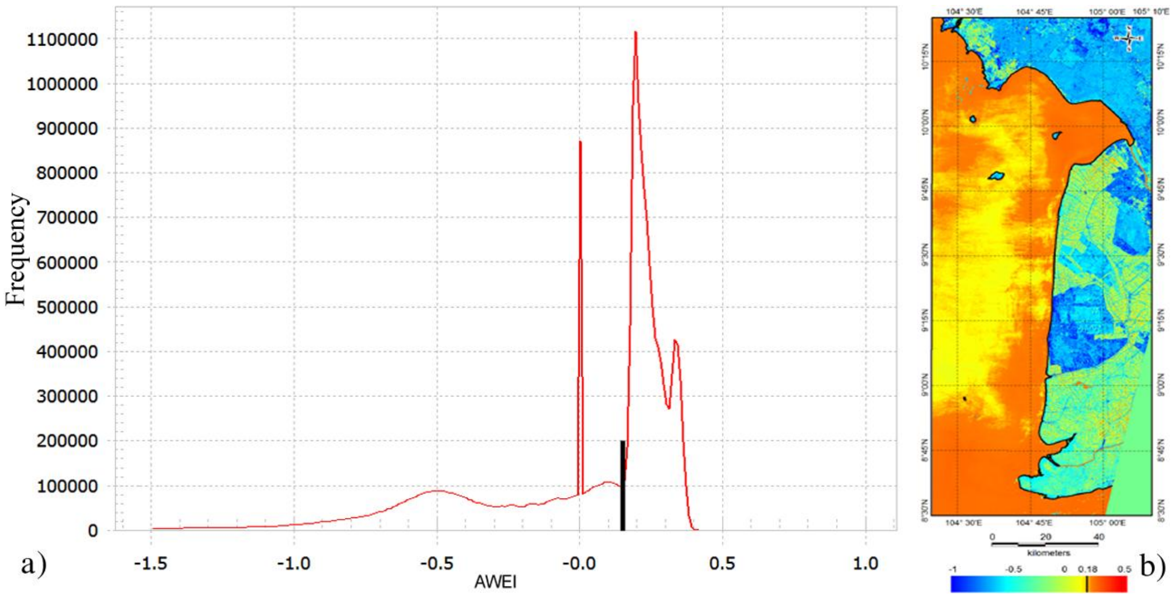

Fig. 6. a) AWEI value distribution chart, b) Shoreline extraction from AWEI

Tide influence on shoreline extraction. The tidal regime in the study area is diurnal inequality, with the high spring tides of 0.8–1.2 m. At the scene acquisition time, the tide level at the Rach Gia station was 0 cm and matched the shoreline position defined from long term mean tide level. Hence, the spontaneous shoreline extracted from the scene 126-53 matched with the shoreline defined from long term mean tide level without tidal coordination. In the scene 126-54, the tide level at the scene acquisition time was -19 cm lower than mean tide level. Most of the shoreline in the scene 126-54 was covered by mangroves. Accuracy calculation of error between field survey groundtruthing for practical shoreline position and spontaneous shoreline extraction is negligible, therefore the tidal level of -19 cm has inconsiderable influence on the result of shoreline extraction from satellite images.

Accuracy assessment of shoreline extraction results. The accuracy of shoreline extraction using water indices (NDWI, MNDWI and AWEI) was evaluated by mean absolute error and root mean square error (formulas 4, 5, respectively) based on groundtruthing positions located during field survey. The distances from groundtruthing location to nearest correspond-ding satellite-derived shorelines using 3 water index approaches (NDWI, MNDWI and AWEI) were measured and calculated using GIS tools. The calculated distances and accuracy assessment result are shown in table 3.

According to assessment results shown in table 3, the errors of satellite-derived shoreline using water index approaches to practical shoreline position located in field survey frequently lied in the acceptable range (lower than 30 m - which is equivalent to the spatial resolution of Landsat 8 imagery). Therefore, the satellite-derived shoreline using three water index approaches (NDWI, MNDWI, AWEI) has the desirable error which is positively appropriated for shoreline shifting study. However, the accuracy assessment results showed that the satellite-derived shoreline using the AWEI approach is the most precise, with the smallest mean absolute error and root mean square error of 12.4 m and 14.8 m, respectively. The satellite-derived shoreline using the MNDWI approach ranked the second with error results of 17.6 m and 22.9 m, meanwhile the NDWI produced the greatest errors of 18.1 m and 23.1 m for their respective mean absolute error and root square error. As a consequence, the satellite-derived shoreline using the AWEI approach is proven as the most appropriate extracted shoreline at the scene acquisition time based on the accuracy assessment results.

Table 3. Accuracy assessment of the shoreline extraction using water indices

No.	Longitude	Latitude	Distance to practical shoreline (m)		
			NDWI	MNDWI	AWEI
1	104.486	10.3725	36	25	21
2	104.509	10.349	4.8	8.3	8.8
3	104.529	10.3175	0.8	4.8	9.5
4	104.557	10.2859	14.5	38.9	13.9
5	104.587	10.2376	7	21.4	3.5
6	104.609	10.1632	27.7	3.1	2.4
7	104.616	10.1482	23.4	35.6	19.2
8	104.637	10.1412	4.6	8.3	16.4
9	104.699	10.2096	9.8	8.5	2.4
10	104.864	10.1115	40	30	20
11	105.076	10.011	42.7	29.2	23.4
12	104.891	9.83303	12.3	28	8.5
13	104.869	9.74345	6.2	9.2	17.8
14	104.84	9.5697	6.5	9.4	17.8
15	104.826	9.34187	22.4	6.2	6.2
16	104.809	9.17564	1.7	2.2	14.4
17	104.816	9.03527	36.6	9.7	5
18	104.795	8.86299	42.3	13.3	28
19	104.802	8.72499	11.2	61.2	20.7
20	104.721	8.60594	1.1	6.9	0.3
21	104.985	8.60417	27.6	10.2	0.2
Mean absolute error			18.1	17.6	12.4
Root mean square error			23.1	22.9	14.8

Discussion

The determination of water body boundaries with other land cover types using water indices based on remote sensing data has been proposed in numerous studies. Nevertheless, each water index approach applied for a certain type of data produces outcomes with distinctive accuracy grades. The latter proposed water indices are proven with higher precision compared to their precedents, and the new sensor OLI/TIR mounted on Landsat 8 vehicle is better than the earlier TM/ETM+ with many empirical evidences worldwide [11]. Besides, the definition of proper threshold to distinguish land-water boundary with the highest desirable accuracy is a time-consuming challenge because its context is dependent on local geography and scene acquisition time [9]. Therefore, the analysis strategy for calculating reflectance of water on different bands will fluctuate depending on the geographical settings and water body conditions. With the three water index approaches used in the study, their original formulas define the threshold for land-water distinction at 0 in the ideal conditions where water is transparent and absorbs most of infrared spectrum. The nearshore water of Vietnam Southwest coast contains large concentration of suspended material and causes higher reflectance, hence the threshold value to distinguish water-land boundary is always greater than 0. As shown in the value distribution charts, the abrupt points are patently obvious for all three water indices, thus the differentiation of water - land boundary using the water index value distribution charts could be positively considered as a reliable approach with high precision.

CONCLUSIONS

In this research, the reflectance of Landsat 8-OLI was applied to calculate water indices following 3 approaches as NDWI, MNDWI and AWEI. Value distribution charts of water indices visualized the boundaries between water and land with corresponding stable thresholds of NDWI, MNDWI and AWEI at 0.12, 0.17 and 0.18, respectively.

At the scene acquisition time, the tide level in the study area was relatively low at Rach Gia station (0 cm) and Song Doc station (-19 cm). The coast was mainly covered by thick mangrove forest, hence the tidal influence on shoreline extraction was insignificant and it is not necessary to perform tide coordination for the results.

Accuracy assessment results including mean absolute error and root mean square error on the satellite-derived shorelines using three water index approaches with 21 groundtruthing positions were within an acceptable range of less than 30 m equivalent to spatial resolution of Landsat 8-OLI images. The satellite-derived shoreline using AWEI approach produced the highest accuracy with mean absolute error of 12.4 m and root mean square error of 14.8 m, therefore it was considered the most appropriate approach for shoreline extraction at the scene acquisition time.

Acknowledgments: The authors would like to thanks the support by the Vietnam Aerospace Science and Technology Program (2016–2020), the granted project code is VT-UD.01/16–20.

REFERENCES

[1] Van Cuong, C., Russell, M., Brown, S., and Dart, P., 2015. Using Shoreline Video Assessment for coastal planning and restoration in the context of climate change in Kien Giang, Vietnam. *Ocean Science Journal*, **50**(2), 413–432. Doi:10.1007/s12601-015-0038-9.

[2] Hung, L. M., Khang, N. D., and Chuong, L. T., 2011. Southerncoastal erosion and accretion from Ho Chi Minh city to Kien Giang-causes and protection solutions. *Journal of Water Resources Science and Technology*, (2), 2–9.

[3] Tran Anh Tuan, Le Dinh Nam, Vu Le Phuong, Nguyen Thi Anh Nguyet, Pham Viet Hong, Nguyen Thuy Linh, Dieu Tien Bui, 2016. Shoreline Change Detection in the Southwest Region of Vietnam from 1999 to 2016 Using GIS and Remote Sensing Data. *Proceedings of the International Conferences on Earth Sciences and Sustainable Geo-Resources Development* (ESASGD 2016). *Transport Publishing House*, Pp. 137–144.

[4] Bouchahma, M., Yan, W., and Ouessar, M., 2012. Island coastline change detection based on image processing and remote sensing. *Computer and Information Science*, **5**(3), 27–36.

[5] Liu, H., and Jezek, K. C., 2004. Automated extraction of coastline from satellite imagery by integrating Canny edge detection and locally adaptive thresholding methods. *International Journal of Remote Sensing*, **25**(5), 937–958.

[6] Winarso, G., and Budhiman, S., 2001. The potential application of remote sensing data for coastal study. In *Proc. 22nd. Asian Conference on Remote Sensing, Singapore* (Pp. 1–5).

[7] McFeeters, S. K., 1996. The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing*, **17**(7), 1425–1432.

[8] Xu, H., 2006. Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *International Journal of Remote Sensing*, **27**(14), 3025–3033.

[9] Feyisa, G. L., Meilby, H., Fensholt, R., and Proud, S. R., 2014. Automated Water Extraction Index: A new technique for surface water mapping using Landsat imagery. *Remote Sensing of Environment*, **140**, 23–35.

[10] Willmott, C. J., and Matsuura, K., 2005. Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. *Climate research*, **30**(1), 79–82. Doi:10.3354/cr030079.

[11] Zhai, K., Wu, X., Qin, Y., and Du, P., 2015. Comparison of surface water extraction performances of different classic water indices using OLI and TM imageries in different situations. *Geo-spatial Information Science*, **18**(1), 32–42. DOI: 10.1080/10095020.2015.1017911.