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Comparison of shoreline extraction indexes performance using Landsat 9 satellite images in the heterogeneous coastal area

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Abstract

In this study, automatic shoreline extraction was performed using different indexes in the coastal region containing different land cover types and their performances were compared. For this purpose, Landsat 9 Satellite images, the newest satellite of Landsat, were used. Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Automated Water Extraction Index (AWEI), Water Ratio Index (WRI), and Normalized Difference Moisture Index (NDMI), which are frequently preferred in the literature, are used automatically to determine the shoreline. The obtained shorelines were compared with the reference shoreline and their performances were evaluated. In the performance evaluation phase, the behavior of the shoreline inference indices in different land cover types adjacent to the shore was examined and their advantages and disadvantages compared to each other were revealed. The results showed that AWEI, NDWI, WRI, NDMI and NDVI gave the most accurate results in automatic shoreline inference across the study area, respectively. Although AWEI still gives a high accuracy in different land cover types, it is seen that the accuracy of NDVI increases in the region where vegetation is adjacent to the shore.

1. Introduction

Coastal regions, where a large part of the world's population live, are changing rapidly due to their dynamic structure. Various natural and cultural factors accelerate this change, and therefore, obtaining up-to-date information about coasts quickly and reliably is of great interest (Zollini et al. 2019; Demir et al. 2016). The priority in determining the change in coasts is the determination of the coastline. Accurate determination of the shoreline, coastal zone management, etc. extremely useful for various applications (Ghorai and Mahapatra 2020).

Coastline extraction with conventional methods is very difficult, costly, time consuming and sometimes impossible for the entire coastal system (Aedla et al. 2015). In this context, coastlines can be detected quickly and accurately with the integration of Geographic Information System (GIS) and Remote Sensing (RS) technologies (Selim et al. 2016; Hossain et al. 2021). Automatic shoreline extraction indexes also make this detection much easier. However, it is known that different land cover types adjacent to the shoreline directly affect the performance of the indexes used in the shoreline extraction (Li and Gong 2016; Wicaksono and Wicaksono 2019; Selim et al. 2021). Therefore, advantages and disadvantages of shoreline inference indexes on non-homogeneous shores constitute the motivation of this study. In this study, the performances of the shoreline extraction indexes, which are frequently used in the literature, on the inhomogeneous coastal region were compared. In this context, Landsat 9 satellite images, the newest satellite of Landsat, were used. Using edge detection technology, Landsat 9 collects the highest quality data ever recorded by a Landsat satellite (Masek et al. 2020; NASA 2021). Landsat 9 carries two devices, Operational Land Imager 2 (OLI-2) and Thermal Infrared Sensor 2 (TIRS-2) (Masek et al. 2020). These devices are optical sensors that detect 11 wavelength bands of visible, near infrared, shortwave infrared, and thermal infrared light as it is reflected or emitted from the planet's surface (NASA 2021). Data from these devices can be accessed free of charge. The OLI sensor that produces images used in this study has 9 bands, 8 of

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which are 30 m ground sample distances (GSD) and 1 is 15 m GSD.

Among the shoreline extraction indexes that can be calculated using relevant bands of Landsat 9, Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Automated Water Extraction Index (AWEI), Water Ratio Index (WRI) and Normalized Difference Moisture Index (NDMI) were calculated, the performances and accuracy of these indexes were compared.

2. Method

The working method consists of 4 basic stages: area definition, data preparation, index calculation and the accuracy analysis.

2.1. Study area

The study was carried out in Antalya Province, which is one of the most important tourism destinations in Turkey and known for its coastal regions. The working area is located at 36°53'1.04"N and 30°41'14.30"E (Figure 1).

Figure 1. Location of the study area

The coastline covering the study area is approximately 8.5 km long. The land uses adjacent to the coastline, on the other hand, show different characteristics. In this context, approximately 3 km of it consists of sand dunes, 4 km of which consists of stony-rocky and the remaining 1.5 km of which consists of vegetation cover.

2.2. Data preparation

In the study, Landsat 9 satellite images on 28 April,2022 which can be accessed free of charge, were used. Landsat's newest satellite, Landsat 9, has a resolution of 30 m and has 9 bands. Atmospheric correction was applied to the images using Quantum GIS (QGis 3.6.3) software and they were made ready for analysis.

2.3. Shoreline Extraction Indexes

In this study, shoreline extraction indexes, which are frequently preferred in the literature, were used and their performances were compared.

2.3.1 NDVI

The Normalized Difference Vegetation Index is an index that reveals the density of vegetation by analyzing its health or unhealthy state. It is also used in shoreline extraction (El Kafrawy et al. 2017; Gonçalves et al. 2019). The NDVI formula is shown below.

$$NDVI = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}$$

2.3.2 NDWI

The Normalized Difference Water Index is used to highlight open water features in satellite images and allows a body of water to be highlighted against soil and vegetation (Xu 2006). It also effectively measures the moisture content (McAllister et al. 2022). NDWI is calculated by the following method;

$$NDWI = \frac{\text{Green} - \text{NIR}}{\text{Green} + \text{NIR}}$$

2.3.3 AWEI

Automatic Water Extraction Index enables shoreline determination by increasing the contrast between water and other surfaces, maximizing the separability of water and non-water pixels (Feyisa et al. 2014). Index formula shows as below:

AWEI = 4 x (Green-SWIR2) - (0.25xNIR+2.75xSWIR1)

2.3.4 WRI

The Water Ratio Index is an index based on the dominant spectral reflection of water in the green and red bands and using 4 spectral reflectance bands (Guatam et al. 2015). The formula shown as below;

$$WRI = \frac{\text{Green} + \text{Red}}{\text{NIR} + \text{SWIR}}$$

2.3.5 NDMI

The Normalized Difference Moisture Index is often used to determine vegetation water content. It is calculated as the ratio between NIR and SWIR values (Naik and Anuradha 2018). The formula show as below;

$$NDMI = \frac{\text{NIR} - \text{SWIR}}{\text{NIR} + \text{SWIR}}$$

2.4. Performance Analysis

First of all, the reference coastline was obtained by precisely drawing the coastline of the study area with manual digitation on the Google Earth satellite image. Then, each index was calculated using the relevant bands of the Landsat 9 image and the shorelines were automatically extracted. The extracted shorelines were converted into points with a distance of 30 m based on the pixel resolution, and nearest analysis was applied with the reference shoreline. Then, the mean and standard deviation values were calculated with the following formulas and their performance was evaluated.

Mean formula	Standard deviation formula	Median formula
$\bar{x} = \frac{\sum x}{N}$	$s = \sqrt{\frac{\Sigma(x-\bar{x})^2}{N-1}}$	$\mu\,(x) = \frac{\mathrm{N}+1}{2}$

here;

$\bar{x}$: arithmetic mean of values
s : standard deviation
x : each shoreline value
μ : median
$\sum x$: the sum of x
N : number of data

3. Results

In the study area, where different land covers are adjacent to the coast, the coastline was automatically determined and mapped on the Landsat 9 images of the water-based indexes (Figure2).

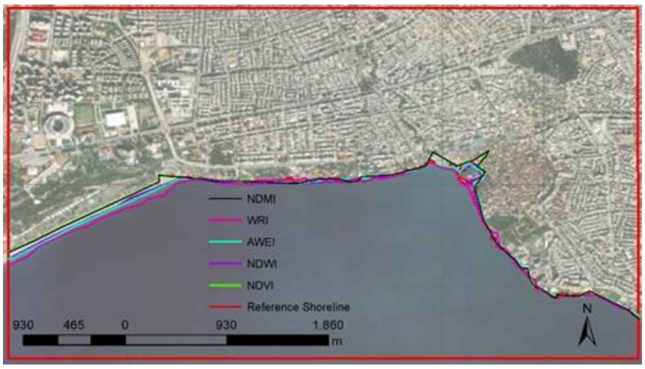

Figure 2. Shorelines created with indexes

In the map created, it is seen that for 5 different index coastlines can be drawn automatically, but there are differences in certain regions. Indexes that give the closest and farthest results based on the reference coastline are shown with mean, median and standard deviation in Table 1.

Table 1. Index performance data

Indexes	**Mean (m)**	**Median (m)**	**Standart deviation (m)**
AWEI	6,256	4,441	5,284
NDWI	8,883	6,661	6,694
WRI	18,814	13,053	17,527
NDMI	20,873	7,864	26,568
NDVI	21,071	8,168	26,585

As can be seen from the table, it is understood that AWEI is the most compatible index with the reference coastline in the relevant study area. The AWEI index automatically determined the shoreline in the best way with an average difference of 6 m and a standard error about 5 m. Then, NDWI gives the best result by about 9 m. Again, the standard error of NDVI has a value similar to the AWEI. It is understood that these two indices are very close to the reference line with their median values of 4.4 m and 6.6 m, respectively. WRI gives the best result following these indexes. It is seen that mean, median and standard deviation are high in this index. NDMI with a mean value of 20,873 m and NDVI with a mean value of 21,071 m gave the worst results in the related field. The median and standard deviation values of NDMI and NDVI were also quite high. Related indexes differ in areas where different types of land cover are adjacent to the coast. In the area where the waterline is adjacent to the dune, AWEI and NDWI give the closest results, while other indexes seem to be quite far from the reference shoreline (Figure 3).

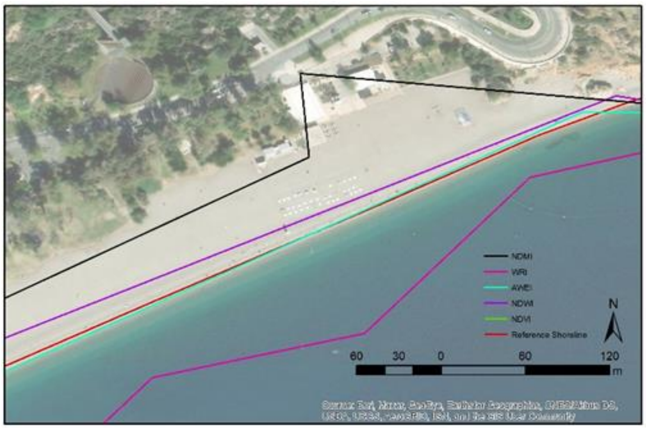

Figure 3. Behavior of indexes on the beach coast

In the area where the stony-rocky land cover borders the waterline, it is seen that WRI is superior to other indexes (Figure 4). In this region, other indices show similar behaviors.

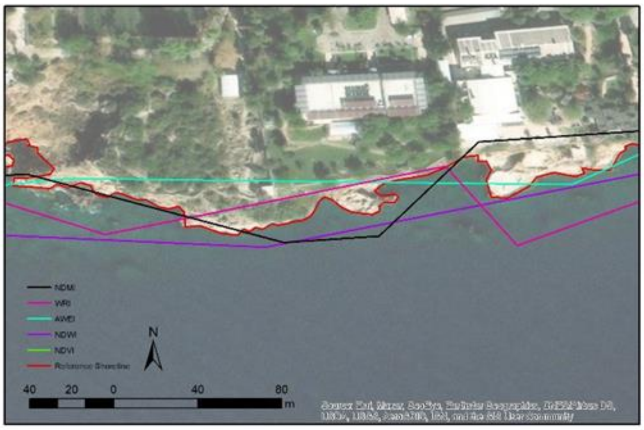

Figure 4. Behavior of indexes on the rocky shore

In the parts where the vegetation cover is adjacent and close to the waterline, WRI gave the worst results, in this part NDMI and NDVI showed results close to the shoreline (Figure 5).

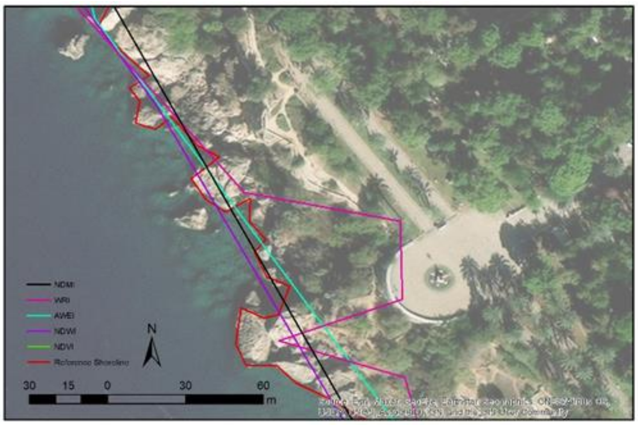

Figure 5. Behavior of indices on the vegetation shore

The obtained results show that in the study area where there are different land cover types adjacent to the coast, when the entire study area is evaluated, indexes that best extract the coastline are AWEI, NDWI, WRI, NDMI and NDVI, respectively.

4. Discussion and Conclusion

In the study area where different land cover types border the waterline, the performance of the shoreline extraction indexes were compared, and it was seen that AWEI and NDWI were more advantageous than other indexes in the whole area. According to Selim et al. (2021) stated that AWEI gave better results compared to other indexes El Kafrawy (2017) stated that NDWI provides higher accuracy than NDVI in the coastline extraction. In the literature, the results of many studies using shoreline extraction indices are largely in line with this study. However, since NDVI and NDMI make a classification based on moisture content, it has been observed that they do not produce very good results in shoreline extraction (Magloine et al. 2014). It was determined that the accuracy of NDVI and NDMI slightly increased only in the vegetation cover adjacent to the waterfront, and in this context, it was predicted that it could be used in a controlled manner in such areas.

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