SHORELINE EXTRACTION USING UNSUPERVISED CLASSIFICATION ON SENTINEL-2 IMAGERY

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ABSTRACT

Shoreline extraction is a key process for many coastal zone applications, such as navigation and coastal environmental protection. The manual extraction of shorelines manually is tedious and subject to the operator's ability. The main objective of this research is to evaluate the use of two different image fusion techniques (IHS and PCA - Principal Component Analisys) using near-infrared band on multispectral Sentinel-2 imagery to extract shoreline in the coastal zone of Cassino beach, Southern Brazil. The resulting images were classified into two classes (water and non-water) using the K-Means algorithm, and the accuracy was evaluated through the analysis of mean absolute difference and RMSE applied on segments of artificial coastal structures. The results indicate that the shoreline extraction by PCA method obtained the most accurate results, and the use of sharpened MNDWI (Modified Normalized Difference Water Index) image shows a good alternative to improve shoreline extraction.

Key words – *Shoreline extraction, Sentinel-2 MSI, Image Fusion, MNDWI, K-Means.*

1. INTRODUCTION

The coastal zones are economically and environmentally important regions. It is estimated that about 40% of the human population lived in the area around 100 km of the coastal zone, and that more than 60% of the largest cities in the world are located in the coastal zone [1]. The undue occupation of the coastal regions has caused damage to the local ecosystem, such as changes in the shoreline, that consequently intensifies erosive processes. According to [2] the shoreline is defined as the physical interface between land and water. Shoreline extraction is used in a variety of applications, such as coastal zone management and navigation safety. However, determining the shoreline is a difficult task, because of seasonal variations, caused by waves, winds, coastal currents, storms, and others.

The most common methods for shoreline extraction involve visual interpretation from conventional ground surveys or aerial photographs [2, 3]. These methods are, by definition, subjective and depend on the interpreter's individual abilities, often requiring the operator to be familiar with the locale [2]. Using tidal datum indicators is a better method to identify the shoreline, but it's limited when determining the historical shoreline [3]. In recent years, there has been an increase in the use of remote sensing data using optical and synthetic aperture radar (SAR) satellites to extract and mapping the shoreline automatically or semi-automatically [4]. Several methods have been proposed to accurately locate the position of the shoreline and are based on the use of supervised and unsupervised classification or thresholding techniques [5–7]. Regardless of the method the classification of the pixels in water or land will depend, among other factors, on the resolution of the input data used.

Multispectral satellite imagery offers several advantages, such as a large number of data records and the availability of repeated images of a single place at different times [5]. Thus, multispectral satellite imagery are potentially useful for recognizing changes in the medium and long term. Very high spatial resolution (VHSR) multispectral imagery (e.g., Ikonos, WorldView-2) are able to capture the shoreline with greater precision [3]. The use of such images for mapping on a regional scale and with a long series of data may be cost-prohibitive though. Medium-resolution imagery (eg, Landsat-8, Sentinel-2, CBERS-4) can be used to determine the shoreline with good cost-benefit and provide a long-time series. However, because the spatial resolution of these sensors is relatively low to detect most changes in the shoreline within the time scale required for coastal management, they have their use is limited [5].

The use of image fusion techniques, such as pansharpening, can improve the spatial resolution of multispectral bands for the same resolution of panchromatic band, preserving the spectral information of the multispectral image [8]. Satellites such as Landsat-8 and CBERS-4 provide panchromatic images with higher spatial resolution than their multispectral images. A large number of fusion techniques have been developed to combine panchromatic and multispectral images to produce an improved multispectral image in high spatial resolution [9–11]. The Sentinel-2 mission carries a Multispectral Instrument (MSI) with 13 spectral bands that acquires observations over global terrestrial surfaces with a revisit frequency of approximately 5 days and high spatial resolution. Sentinel-2 MSI imagery includes 10 m resolution green and near infrared (NIR) bands and 20 m resolution short-wave infrared (SWIR) bands, which can be combined to produce spectral water indexes that facilitate the extraction of water bodies.

Two water indexes, in particular, have been widely used for shoreline extraction: Normalized Difference Water Index (NDWI), proposed by [12], using the green and NIR bands, and Modified Normalized Difference Water Index (MNDWI), proposed by [13], that uses the SWIR instead of NIR, the latter being more efficient for enhance the water information. However, since that the spatial resolutions of green and SWIR bands are different, and Sentinel-2 MSI no longer provides panchromatic band imagery, MNDWI can only be obtained in 20 m resolution. [14] proposed the use of the high resolution band to sharpen other multi-spectral bands, such as red and

NIR bands that are most related to SWIR.

This study evaluates the shoreline extraction in multispectral images obtained from Sentinel-2 MSI using two image fusion techniques (IHS - Intensity Hue Saturation and PCA - Principal Component Analisys) to obtain MNDWI and NDWI in the resolution of 10 m, and unsupervised classification using K-Means algorithm to distinguish two regions (water/non-water) in the composition of water indexes and NIR band. The study area corresponds to Cassino beach, Southern Brazil. The accuracy of the classification will be performed through the analysis of mean absolute difference and RMSE applied on segments of coastal artificial constructions that have constant and well-defined land-water interfaces.

2. MATERIAL E METHODS

A portion of Cassino beach, Southern Brazil, was used as study area, as shown in Figure 1. The beach is located in the city of Rio Grande, in the proximity of Patos Lagoon inlet, and as such has several anthropogenic activities such as fishing, tourism and port activities. The beach is classified as sandy, has an extension of 200 km southward, presenting a micromareal regime in the first 30 km and being considered morphodynamically as dissipative [15]. Near to the beach, in both banks of the Patos Lagoon inlet, two 4-km long jetties were constructed to stabilize the inlet. These fixed artificial structures will be used as reference for evaluating the effectiveness of the shoreline extraction proposed by this study.

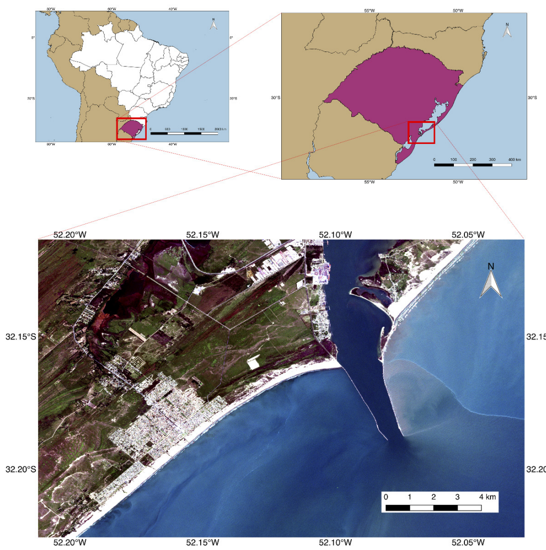

Figure 1: Study area in RapidEye imagery: Brazil (upper-left), Rio Grande do Sul state (upper-right) and Cassino Beach (bottom) (R: Band 3; G: Band 2; B: Band 1).

One Sentinel-2 Level-1C MS image, covering an area of 100 km x 100 km, were used for a shoreline extraction. The Sentinel-2 Level-1C product has radiometric and geometric corrections, including ortho-rectification and spatial registration with sub-pixel accuracy. It provides the top-of-atmosphere (TOA) reflectance in the UTM/WGS84 projection. An image acquired on February 17, 2018 was downloaded in the JPG2000 format of Sentinel-2 Pre-Operations (http://scihub.copernicus.eu), and then converted to the GeoTIFF format. Moreover, one RapidEye Level-3A MS image was used to extract the reference shoreline. The RapidEye Ortho Level-3A product consists of a constellation of 5 satellites launched in 2008 by the German company RapidEye AG and now operated by the Planet (https://www.planet.com/). The product has radiometric, geometric and terrain corrections, including ortho-rectification. It provides top-of-the-atmosphere (TOA) radiance in the UTM/WGS84 projection. The image acquired on July 25, 2015 was downloaded in Planet's site in the GeoTIFF format. The multi-spectral bands contained in the products, as well as their respective spatial resolutions, are present in Table 1.

Satellite	Bands	Spatial Resolution (m)	Range Spectral (nm)
Sentinel-2B	1	60	421-457
	2	10	439-535
	3	10	537-582
	4	10	646-685
	5	20	694-714
	6	20	731-749
	7	20	768-796
	8	10	767-908
	8A	20	848-881
	9	60	931-958
	10	60	1338-1414
	11	20	1539-1681
	12	20	2072-2312
RapidEye	1	5	440-510
	2	5	520-590
	3	5	630-685
	4	5	690-730
	5	5	760-850

Table 1: Specifications of Sentinel-2 and RapidEye imagery.

The shoreline extraction from the Sentinel-2 MS image was performed using an unsupervised classification approach by K-Means using as attributes two spectral water indexes, NDWI and MNDWI, and a spectral band. In pre-processing, the RapidEye bands were converted to TOA reflectance. In addition, atmospheric correction was performed on both images using the DOS1 algorithm [16] to convert TOA reflectance to surface reflectance. The NDWI can be calculated directly from bands 3 (green) and 8 (NIR), at a resolution of 10 m. The MNDWI is obtained in a similar way to the NDWI, but using the SWIR band in place of the NIR band. For Sentinel-2, the green band has a spatial resolution of 10 m, while the band in the SWIR (band 11) has a spatial resolution of 20 m. MNDWI can then be calculated at a resolution of 20 m by degrading band 3 at a resolution of 20 m or obtained at a resolution of 10 m by using a pansharpening algorithm in band 11. The second method will be used. Five 20 m bands (Bands 5, 6, 7, 11 and 12) were used in pan-sharpening algorithms (IHS and PCA), using 10 m band 8 as most suitable pan-like band [14]. Moreover, band 8 was used to complete the set of attributes used in the classification. After classification, three classes were obtained: water, vegetation, and soil/concrete. The vegetation and soil/concrete classes were grouped into a single class,

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non-water, and then the final binary map (water/non-water) was vectorized and the shoreline drawn from the edges.

For the extraction of the reference shoreline from the RapidEye MS image, a unsupervised classification approach by K-Means was also performed using as attributes a water spectral index, NDWI, obtained directly from bands 2 (green) and 5 (NIR), and band 5. After classification, three classes were obtained: water, vegetation, and soil/concrete. The vegetation and soil/concrete classes were grouped into a single class, non-water, and then the final binary map (water/non-water) was vectorized and the shoreline drawn from the edges. The detailed methodology of the study is described in Figure 2.

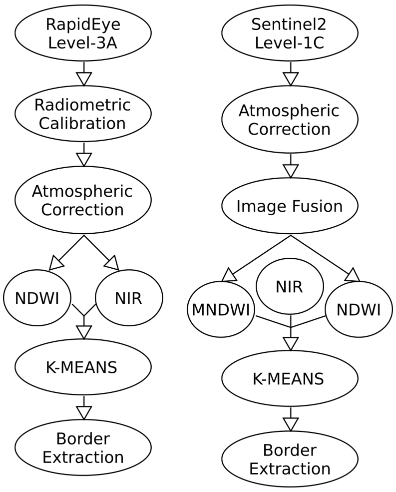

Figure 2: Shoreline extraction workflow

A quantitative analysis of the quality of the shoreline extraction from Sentinel-2 will be performed using four measures: the mean absolute difference (MAD), the root mean square error (RMSE), and the absolute and maximum absolute difference. The absolute difference represents the minimum distance between each point composing the extracted shoreline to the reference shoreline.

3. RESULTS AND DISCUSSION

Following the methodology presented previously, the first result of this work is the Sentinel-2 MNDWI images with resolution of 10 m, obtained by the fusion of the NIR band (10 m) with the band SWIR-1 (20m). In the qualitative visual evaluation, both methods, IHS and PCA, showed good results after the fusion, increasing its level of detail and edges to resolution of 10m, as shown in Figure 3.

Figure 3: Subareas of SWIR band in: Original band (left), IHS fusion (center) and PCA fusion (right).

After the K-Means was applied, the binarized image was generated and, finally, the shoreline was extracted. The results obtained from these steps are shown in Figure 4 side by side for the two fusion methods. The assessment of the shoreline extraction quality was made quantitatively by comparison with the reference of the shoreline extracted by the RapidEye sensor, by calculating the error between the points. The quantitative results of the mean error are given in Table 2.

Fusion method	MAD (m)	RMSE (m)	Variance (m)	Std. Dev. (m)	Minimum AD (m)	Maximum AD (m)
IHS	4.60	5.98	14.65	3.83	0.0	42.72
PCA	4.50	5.72	12.45	3.53	0.0	15.0

Table 2: Summary of shoreline extraction accuracy (MAD = mean absolute difference; RMSE = root mean square error).

By means of this table, it is possible to notice that the proposed algorithm presented satisfactory results, being the RMSE less than 6m for both fusion methods. Since the reference used presents a spatial resolution of 5m, with typical RMSE of 7m. Still analyzing the errors, it is noticed that the method of fusion by Principal Components achieved little better result, about 4.5% in RMSE and 64% in maximum value, than the IHS method. This result was also expected, since this PCA method used more input bands, carrying more information. However, with this small difference of 4.5% in RMSE, it can not be said that the PCA result will always be better than IHS, after all if the additional bands add incoherent information, their result may be lower than the IHS.

Comparing the proposed method with the literature, we can see the quality of the results, since [17] reached RMSE

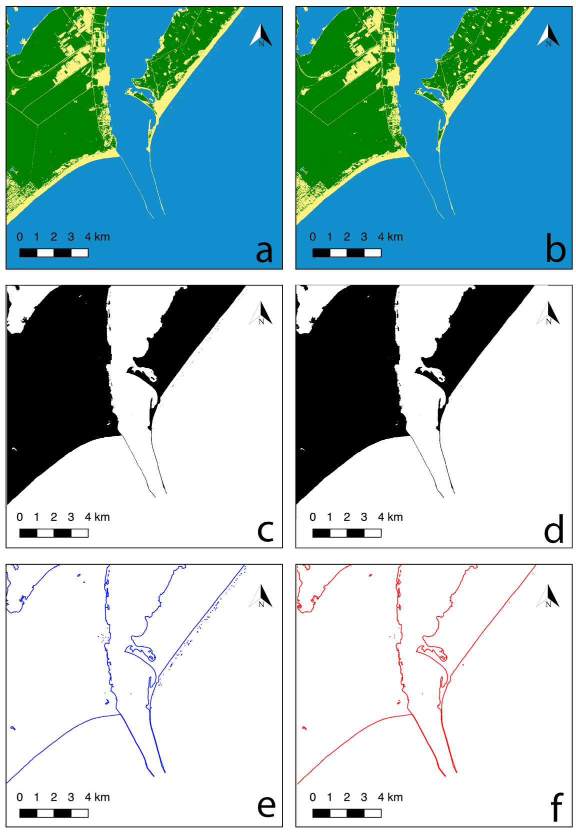

Figure 4: Classified maps using K-Means (a) PCA and (b) IHS fusion; Water/non-water binary maps (c) PCA and (d) IHS fusion; Shoreline extracted from (e) PCA and (f) IHS fusion.

Reference	Proposed method	Liu et al (2017) [10]	Wang et al. (2018) [7]	Taha (2010) [11]
Sensors	Sentinel-2 (20m)	Landsat-8 (30m)	Landsat-8 (30m)	Landsat-8 (30m)
Fusion method	PCA	Gram-Schmidt	RBF + Brovey	IHS
Fusion Band (FB)	NIR (10m)	Panchromatic (15m)	DTPCE (10m)	SAR (6.25m)
Segmentation	K-Means	Super-resolution border	Otsu	Fuzzy
RMSE (m)	5.72	8.80	10.0	6.75
RMSE/FB	0.57	0.59	1.00	1.08

Table 3: Comparison between different methods of shoreline extraction (DTPCE = downscaling-then-pansharpening coastline extracting).

between 3-5 m in comparison to in situ data, although they used the IKONOS sensor high spatial resolution, 82 cm in the panchromatic band and 3.28 m in the visible and near infrared bands. Table 3 compares the results of the proposed method with the results of the literature considering the resolutions, the bands used for the fusion, the fusion and segmentation methods. It is possible to perceive that the proposed method achieved good results, since it was able to represent the coast line with 57% of the resolution of its fusion band, while the best result in the literature [10] represent the coast line with 59% of its fusion band. A subarea containing the shorelines obtained from Sentinel-2 and RapidEye is shown in Figure 5.

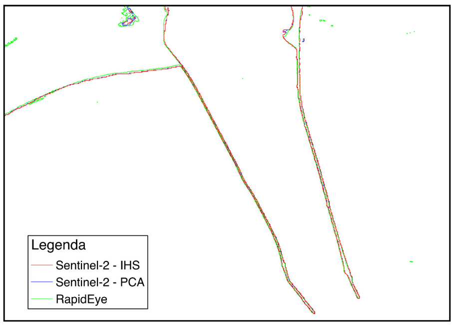

Figure 5: Shoreline extracted from IHS fusion (red), PCA fusion (blue) and reference (green).

4. CONCLUSIONS

In this study, we focused on the development and evaluation of shoreline extraction using Sentinel-2 imagery with IHS and PCA fusion methods, and compared with high resolution image from Rapideye. The results were very similar even when comparing with the Rapideye image. The NDWI and MNDWI were key features for these extraction because they had high contrast between water and non-water regions. Sentinel-2 is a good alternative to shoreline extraction, because of the SWIR band which is used in the MNDWI and due to the free availability of data.

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