Shoreline Delineation in Complex Intertidal Environments using Sentinel – 1 SAR Imagery

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Summary

The threats that climate-change-induced sea level rise pose to coastal communities can be assessed using coastal vulnerability models. In order to be effective, such models require accurate estimates of shoreline position. Such data are rarely available in developing countries. Here, we develop a simple approach based on image thresholding and subsequent vectorisation of Sentinel-1 SAR data for a complex intertidal zone in the Niger Delta, Nigeria, and show how shoreline position varies over space and time under different tidal conditions.

KEYWORDS: Backscatter, Tidal State, Thresholding, Vector Conversion

1. Introduction

In recent years, the coastal environment has experienced considerable pressure due to human activities and extreme climate changes. The risk of climate-change-induced sea-level rise damage to human and economic development in coastal areas is growing. The combined effects of sea-level rise and changes in upstream river discharge, combined with erosion of coastal embankments and changes to natural sediment dynamics, pose severe threats to coastal communities (UNDP, 2010). The Niger Delta region is one the most extensive wetlands in the world threatened by sea-level rise. It is projected that over 250 sq. km of land in the coastal zone of the Niger Delta will be flooded and submerged as a result of one-meter rise in sea level by the year 2100 (IPCC, 2007). Due to the sensitive nature of the region in terms of capital investment, human and natural resources, it is estimated that the region will lose approximately $8.05 billion and $17.5 billion respectively with average sea level rise of 0.2 m and 1.0 m by 2025.

Creating an accurate representation of shoreline position is an essential first step towards establishing the impacts of climate change-induced sea-level rise. Spatial and temporal variation in shoreline position represent critical physical parameters in the modelling of coastal vulnerability. Positional changes over time arise from variations in erosion and deposition as a result of waves and tidal action. High resolution shoreline data are readily available in most developed countries but absent for many developing countries such as Nigeria. Satellite-based approaches offer a sustainable and cost-effective means of providing such information with different measurement techniques based on active and passive systems.

Since the launch of the first earth observation satellite in 1972, optical imagery has been used to derive information on shoreline position. A number of indices have been developed for this purpose including the Normalised Difference Index (NDVI), Normalised Difference Water Index (NDWI), Modified Normalised Water Index (MDWI) and Automated Water Extraction Index (AWEI). (Gudina *et al.* 2014 and Aedla, Dwarakish and Reddy, 2015). However, such indices are less effective in areas where cloud cover dominates for much of the year, or in complex intertidal environments, such as the Niger

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Delta, where the position of the shoreline can change rapidly depending on the state of the tide and/or storm surges. The research challenge, therefore, is to derive positional data that is statistically representative of different environmental conditions.

This research exploits the cloud-penetrating abilities of C-band Synthetic Aperture Radar (SAR) systems mounted on the dual Sentinel-1A and 1B polar orbiting satellites which provide repeat day-night coverage on a 6-day cycle. It uses radiometric thresholding techniques to differentiate between land and water under different tidal states which are then used to construct a continuum of shoreline positional data from low tide to high tide. In subsequent sections of this paper we demonstrate how our method works and illustrate results for different sections of coastline of different complexity under different tidal states.

2. Materials and Methods

Sentinel-1 Level 1 Ground Range Detected (GRD) data were acquired from the European Space Agency (ESA) Copernicus Open Access Hub (https://scihub.copernicus.eu/). Interferogram Wide (IW) sensor images with a swath width of 250km, VV and VH polarisation and 10m spatial resolution were utilised. Time of image acquisition was cross-referenced against state of tide based on predicted data for Bonny, East Niger Delta (https://tides.mobilegeographics.com/locations/843.html). A small number of the images used in this study are summarised in Table 1.

Table 1: Sentinel-1 (GRD) images used in this study showing time of acquisition in relation to predicted tidal state at Bonny, Nigeria.

Date of Acquisition	Time of Acquisition	Predicted Height of Tide (m)
10/11/2018	05:13	2.25
15/11/2018	17:44	0.90
24/10/2019	05:13	1.50
25/08/2019	05:13	0.85

Image pre-processing was performed using the Sentinel Application Platform (SNAP). A generic workflow was adopted to pre-process the radiometric imagery (Figure 1a). Different thresholds were applied to the pixel intensity (backscatter) data in order to determine which best differentiated between land and water for any given tidal state. A threshold of -15 dB was subsequently adopted for all tidal states based on visual inspection of the resulting binary imagery (Figure 1b).

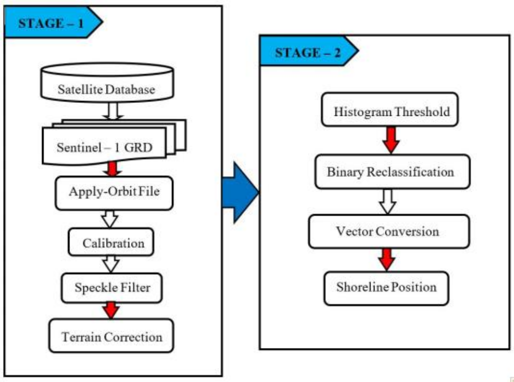

Figure 1a) Image pre-processing in SNAP and b) raster and vector techniques used to determine shoreline position for different tidal states.

3. Results

Figure 2 shows two images for the same part of complex intertidal environment under different tidal states. Histograms, depicting the bimodal distribution of backscattered radar intensity for land and water are also shown. The upper image shows the intertidal zone close to high tide, with a predicted tide of 2.25m at nearby Bonny. The lower image shows the intertidal zone close to low tide, with a predicted tide of 0.85m at nearby Bonny. The shoreline position is similar in some locations but quite different in others.

Figure 3 shows the result of applying a threshold of -15 dB to the backscatter data and vectorizing the subsequent binary (land, water) images. Differences in tidal state are highlighted for Regions of Interest (ROI) A and B. ROI A shows a reasonably consistent definition of a channel under different tidal states with a 10-30m horizontal offset between the 4 lines. ROI B, showing an open stretch of coastline, shows much more variation in shoreline position in contrast for the same tidal range, with horizontal offsets of up to 800m in some locations caused by the emergence (hence inclusion) of offshore bars under low tide conditions. These contrasting examples therefore highlight the challenges of deriving robust estimates of shoreline position in complex intertidal environments.

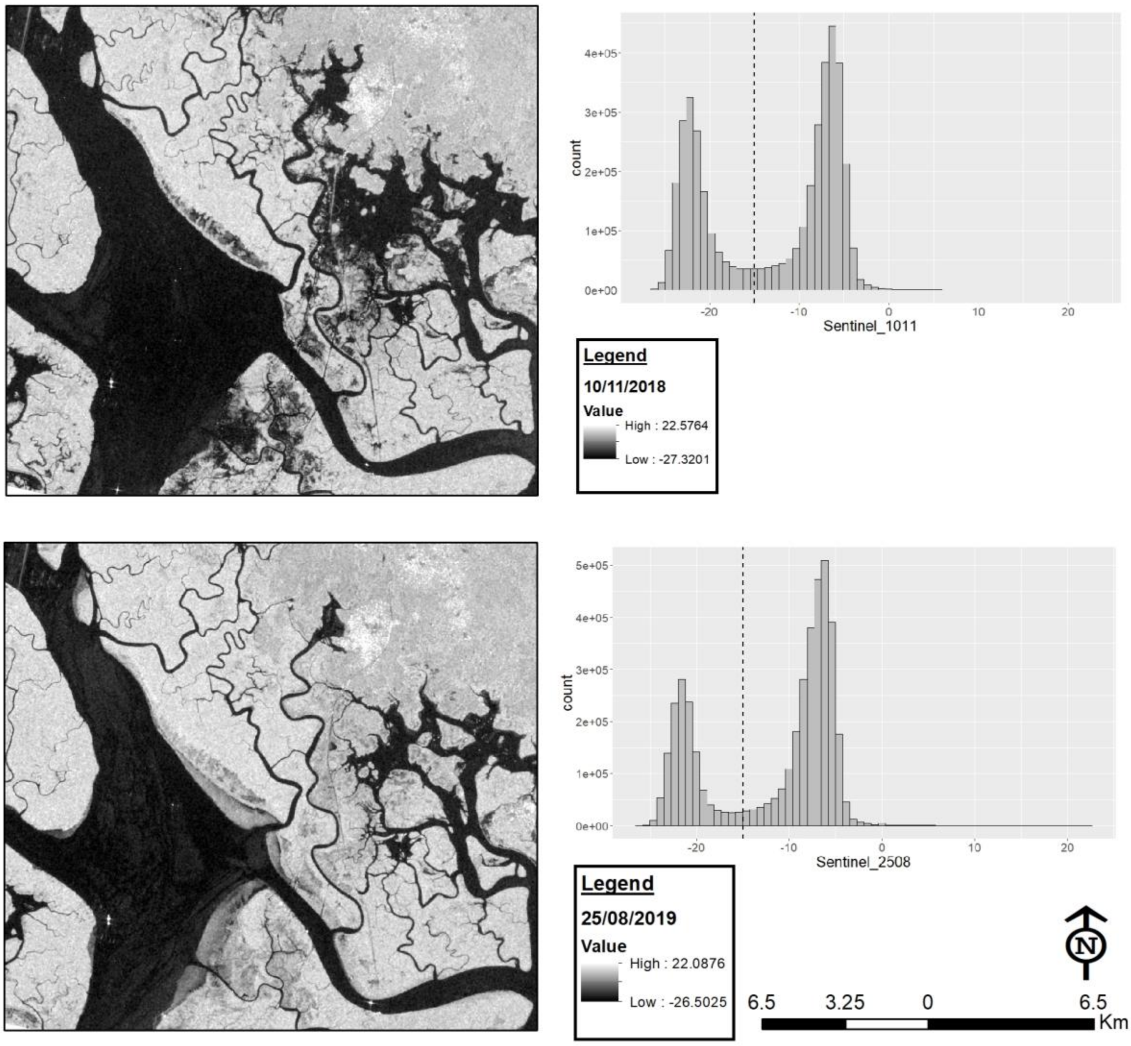

Figure 2. Sentinel-1 backscattered radar intensity (dB) and associated histograms for (upper image) high tide and (lower image) low tide conditions.

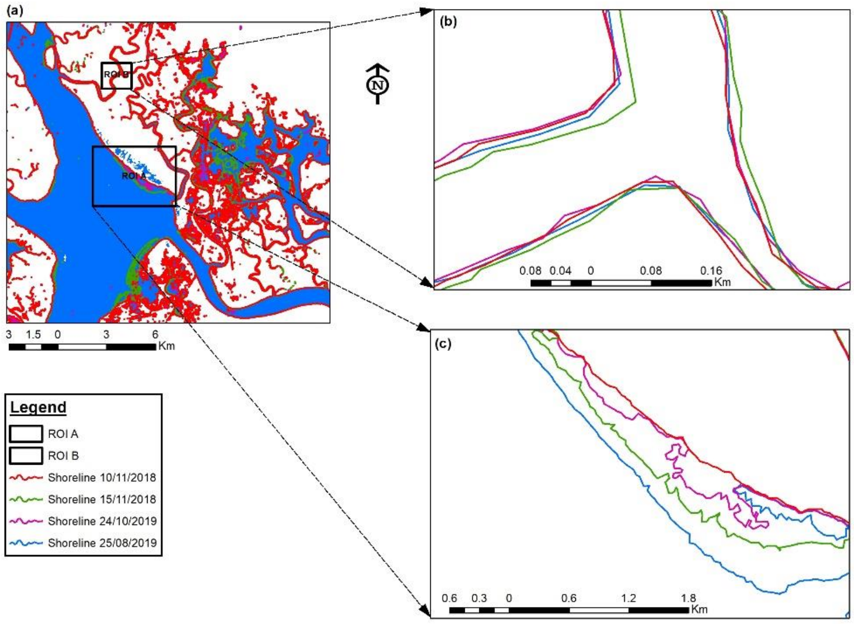

Figure 3. Shoreline positional information for different tidal states (0.85, 0.90, 1.50, 2.25m) based on the processes of image thresholding and vectorisation of the resulting binary images.

4. Discussion and Conclusions

Sentinel-1 SAR imagery was used to differentiate between land and water in a complex intertidal creek region in the Niger Delta under different tidal conditions. Thresholding techniques were then applied to generate shoreline position data with the results showing how the shoreline position and shape vary considerably depending on the state of the tidal cycle. This technique, whilst simple, holds much promise for generating an ensemble of shoreline positional data for different tidal states which can be statistically manipulated and fed into coastal vulnerability models to assess the impacts of sea level change on coastal communities. Future research will focus on developing a more objective means of defining the threshold used to delineate shoreline position and quantifying the characteristics of the resulting linear data. Future research will also focus on the generation of a robust Digital Terrain Model (DTM) from the SAR data since global products such as SRTM and ASTER are too coarse in both horizontal and vertical dimensions and contain too many artefacts to be used to assess coastal inundation in this vulnerable, low-lying part of the world.

5. Acknowledgements

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6. References

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7. Biography

Emmanuel Dike is an early career researcher and second year PhD student within Lancaster Environment Centre (LEC) working on coastal vulnerability assessment in Eastern Niger Delta region, Nigeria. Suzanna Ilic is a Senior Lecturer in coastal processes in LEC with interests in coastal hydrodynamics, sediment transport and morphological changes. Duncan Whyatt is a professor of GIScience in LEC with interests in social and environmental processes. Andrew Folkard is a senior lecturer in LEC with interests in eco-hydrodynamics.