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SPECTRAL CHARACTERIZATION OF THE NIGERIAN SHORELINE USING LANDSAT IMAGERY

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Summary

The challenges of shoreline mapping include the high costs of acquiring up-to-date survey data over the coastal area. As a result, in many developing countries, the shoreline has not been consistently mapped. The variety of methods used for this mapping and the large time differences between the surveys (on the order of decades) could result in inaccuracies in shoreline data. This study presents the development of a shoreline characterization procedure for the Nigerian coastline using satellite remote sensing technology. The study goal is to produce a complete, consistent and continuous shoreline map using publicly available data processed in a GIS environment. A spectral analysis using different satellite bands was conducted to define the land/water boundary and characterize the coastal area around the shoreline. The satellite-derived shorelines were compared to charted shorelines for adequacy and consistency. The procedure was developed based on study sites along the Nigerian coastline. Although the shoreline characterization procedure is developed based on datasets from Nigeria, the procedure should be suitable for use in mapping other developing areas around world.

1. Introduction

Current methods for shoreline mapping include aerial imagery and field surveying that require considerable investments in human and material resources. Mapping and continuous updating of the shoreline for developing countries, like Nigeria, is a challenge (Adegoke et al., 2010). In spite of the huge resources that exist off Nigeria's coast, the shoreline has not been consistently mapped. Most of the information on the Nigerian shoreline is based on 'surveys of opportunity' performed by various government agencies. Additional surveys that are conducted by the multi-national oil and gas companies exploring in the region are typically not available for the use of government agencies. In cases where the data is available, the variety of methods used for shoreline mapping could result in inconsistencies. This paper presents a shoreline mapping and characterization procedure using satellite remote sensing technology over the Nigerian coastline.

The Nigerian shoreline lies on the West Coast of Africa (Figure 1) and is part of the Gulf of Guinea (GoG) (Ibe, 1988; French et al, 1995). The Nigerian shoreline is typically classified into one of the four major coastal groups: barrier island coast, mud coast, Niger Delta coast and the strand coast. The character of the shoreline can be used as an indicator for coastal management. For example, large coastal erosion has been measured in the sandy coastal areas of Lagos (French et al., 1995). For this study, three Nigerian sites were selected based on their coastal characteristics, national priority for mapping and availability in nautical charts and topographic maps. The Lagos study site is a barrier-coast type shoreline with man-made features on both sides of the Lagos inlet. The very sparse vegetation in the Lagos site is comprised primarily of shrubs and short grass. Escravos and Pennington are located in a Niger Delta coast type shoreline. Both sites lie in a densely-vegetated area composed mainly of mangrove and tall shrubs. The mangroves are only present within the channel and extend up to the water line, whereas the coastline is bare of vegetation. Man-made features (moles and oil rigs) are also present in the Escravos study site.

The study goal was to develop a procedure for mapping and characterizing shorelines using publicly-available satellite imagery in a GIS environment. Spectral analysis and image processing algorithms were used to define the land/water boundary and characterize the coastal area around the shoreline. The procedure provided thematic map products at different levels that included: a) land/water delineation, b) major land cover characteristics (natural and man-made) and bathymetry, and c) character attributes of vegetation and exposed land cover. The satellite-derived shorelines were compared to charted shorelines for adequacy and consistency. The satellite-derived shorelines were also compared to shorelines from historical maps to identify any changes between the datasets. A U.S. calibration site and three study sites along the Nigerian shoreline were used for the development of the shoreline characterization procedure.

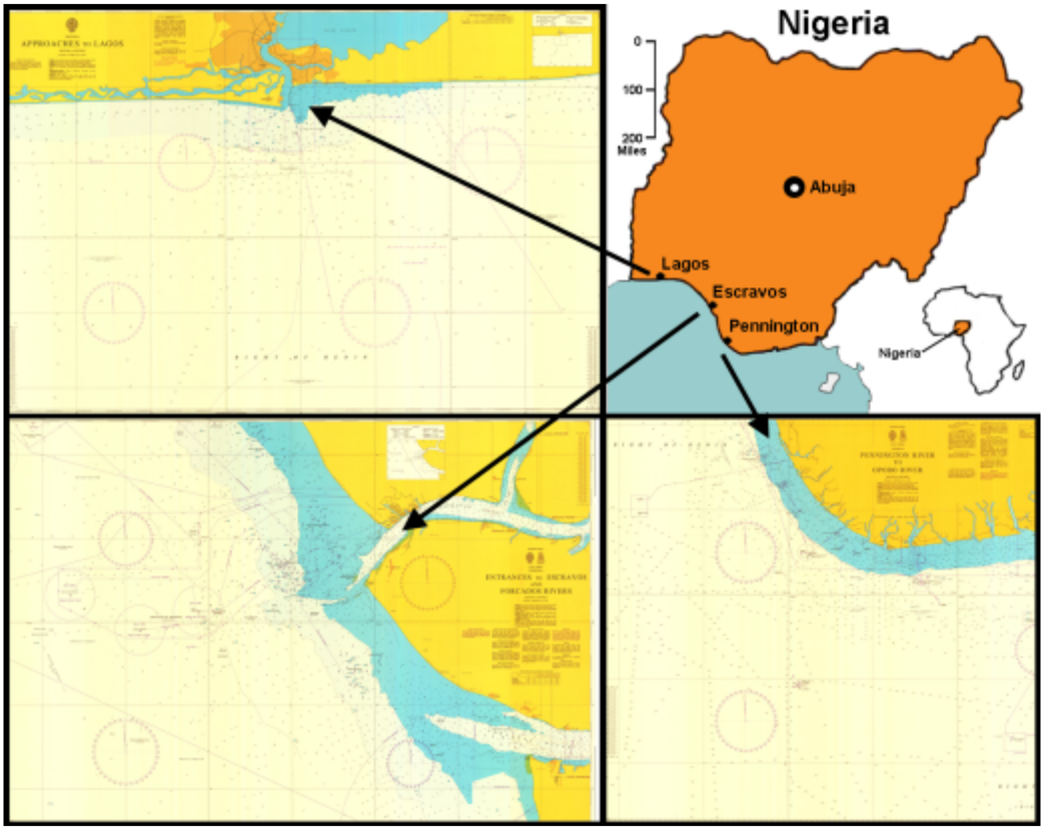

Figure 1. (Top right) Contour map of Nigeria, (Top left) Admiralty Chart of Lagos, (Bottom right) Admiralty Chart of Escravos, and (Bottom left) Admiralty Chart of Pennington.

2. Shoreline position and character

The IHO S–4 publication (IHO, 2011) reviews the symbols and features that are used to describe the shoreline position and character. The land-water boundary, where the shore and water meet (IHO, 1994), is marked on the chart at a selected vertical datum. Typically, the position of the shoreline is defined by a datum that is based on a certain phase of the tide. In many charting organizations, the character of the shoreline can be divided into three main cartographic groups: natural, man-made, and undefined. Natural shorelines refer to coastal areas with a land/water interface that was created naturally without human intervention. Man-made shorelines refer to coastal areas with a land/water interface constructed and designed for a specific purpose (e.g., land protection and berthing). Undefined shoreline typically refers to coastal areas that have not been surveyed. Attributes to natural and man-made shorelines vary between the different hydrographic organizations. However, similar sub-groups are defined based on the physical characteristics of the shorelines. Natural shorelines are typically separated based on their coverage characteristics. A vegetated coastline contains rooted vascular plants such as sea-grass beds, brush, mangroves and trees that are a persistent feature of the coastal landscape (Schwartz, 2005). The exposed shoreline is any natural shoreline that is bare of vegetation in the immediate vicinity of the land/water interface.

Currently, the navigational charts of Nigeria are produced by the United Kingdom Hydrographic Office (UKHO). Three Admiralty Charts at a scale of 1:350,000 cover the whole Nigerian coastline, and only a few key locations (e.g., Lagos and Escravos) are covered by charts at scales larger than 1:80,000. The horizontal datum of the UKHO Admiralty charts is WGS 84 (unknown realization, presumably original), and a Transverse Mercator map projection is used. The vertical datum is Lowest Astronomical Tide (LAT) for soundings, while heights are referenced to Mean High Water Springs (MHWS). Complementary shoreline information is available from topographic maps (without bathymetric information) that were produced in the 1970s by the Federal Surveys, Nigeria. The shorelines were produced from aerial imagery acquired in the mid-1960s and are referenced to Mean Sea Level (MSL). All the topographic maps use Transverse Mercator projections and a datum based on the Clarke 1880 spheroid.

3. Shoreline mapping and characterization procedure

The mapping and characterization of shorelines using multi-spectral satellite imagery was performed in a GIS environment. Key steps in the procedure include (Figure 2): pre-processing, land/water separation (shoreline delineation), water subset analysis (man-made features and bathymetry) and land subset analysis (vegetation and exposed land). Landsat 7 Enhanced Thematic Mapper Plus (ETM+) imagery was used for mapping the position and character of the shoreline. The major consideration in selecting Landsat imagery was the availability of multispectral datasets at no cost for many coastal areas around the world. Other considerations include the satellite revisit cycle, the ease of public access to archives and its absolute calibration. Although the spatial resolution (28.5 m) of Landsat 7 is coarse for shoreline mapping, a goal of the procedure is to provide a reconnaissance tool for future use with higher-resolution multispectral imagery.

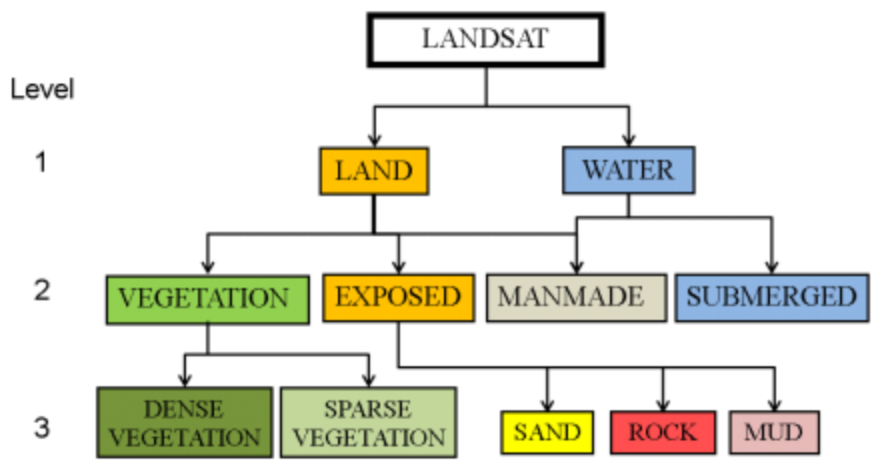

Figure 2. Decision tree hierarchy of the layers generated in the shoreline characterization procedure.

Pre-processing - The pre-processing step includes setting the GIS environment and loading the datasets. The Landsat images were downloaded from the USGS archives (http://earthexplorer.usgs.gov/) based on an archive search criteria that included the geographical coordinates of the area under study, cloud cover, sun glint and date of image. The downloaded Landsat ortho-rectified images have a cover area of 185 km with a 28.5 m pixel resolution and are referenced to WGS 84 with a nominal positional accuracy of better than 50 m. In addition, a lowpass filter was applied to all bands of the Landsat image. This filter was used to smooth all bands of the Landsat image and remove high spatial frequency noise from each image.

Land/water separation - The shoreline extraction was conducted using a single band analysis approach that takes advantage of the difference in the radiance values or DN of land and water in the IR bands. The radiance collected over the water is nearly equal to zero in the IR bands, while most land cover types have higher values (Jensen, 2005). This contrast in radiance values results in a bimodal (double-peaked) histogram of the digital numbers (DNs) for all Landsat bands in the IR region, where a narrow low DN-value peak represents the water and a broad high DN-value peak represents the land. Therefore, a threshold value in the transition zone can be used as a separation of land from water. However, this transition zone is comprised of mixed regimes between land and water as well as sediments with varying moisture content. As a result, the challenge of using a single band analysis method is to find the exact threshold value that best separates land and water while considering temporal and spatial uncertainties related to numerous environmental factors. Band 4 (0.75-0.90 μm) provided the best results for the U.S. calibration site and for the two Nigerian study sites. At the Lagos study site, the success to separate land from water was limited. This might be attributed dust or pollution on the water surface.

Water subset analysis - In order to extract bathymetry accurately, the extraction of man-made features should be conducted first. This is because some of the man-made features are smaller than a pixel area (sub-pixel exposed features) and their spectral characteristics are mixed with submerged areas. These mixed pixels would generate errors in the derived bathymetry results. As a result, the spectral characteristics are observed as shallow water (i.e., submersed feature). In other areas, some man-made features are located in deeper waters (e.g., oil and gas platforms). An IR band-ratio algorithm was utilized to extract land-mixed pixels (natural and man-made features) from the water subset. Extraction of man-made features in the Lagos study site was not trivial. The proximity of these features to the shore, coupled with the turbidity of the Lagos waters, necessitated enhanced manual processing of the Lagos shallow waters. A band ratio using Landsat bands 4 and 7 provided the best results for the extraction of man-made features. In the Escravos study site, the oil rigs were easily extracted using a band ratio because of their distance from land. The regularity of the geometric shape of these rigs and the high algorithm value at the center made it easy to differentiate the features from the irregularly shaped clouds that are also present in the Landsat image.

Land subset analysis - In order to simplify the dataset and reduce the processing time, only the area closest to the shore was classified using a buffer based on the width of the intertidal zone. As an initial approximation, a fixed-width buffer zone of 200 m was created around the shoreline. This value was chosen because it addresses variations in shoreline positions for all sites. A Normalized Difference Vegetation Index (NDVI) band ratio algorithm using the red (band 3) and infrared (band 4) was applied to the land subset for the separation of vegetated from exposed land cover types. After the areas in the land subset were divided into vegetated and exposed land cover types, each group was further classified using unsupervised classification (ISODATA) using six Landsat bands in the classification. This last step in the costal characterization procedure is used as an indicator for coastal areas with different spectral characteristics and requires further investigation for relating these characteristics to physical properties.

4 Comparison results

The satellite remote sensing procedure results were compared to current nautical charts and historical topographic maps. The position and character of the shorelines were manually digitized from the largest scale charts and historical maps available for each study site. In cases where the available largest scale chart did not sufficiently cover the site, a smaller scale chart was utilized. Two shorelines at two different tidal stages were digitized for each chart/map. Good agreement in position was found between the satellite-derived shorelines and the digitized shorelines over the U.S. Calibration site. The position of the satellite-derived shoreline was close to the MHW, indicating that the Landsat image may have been acquired at a higher stage of tide. Archive tidal stage information (from the NOAA CO-OPS website) supports this is conclusion. Unfortunately, only a qualitative cartographic comparison over the Nigerian study could be conducted. Based on consideration of the nominal georeferencing accuracy and resolution of the Landsat 7 imagery, the lack of tide information, and the method of shoreline extraction, the estimated positional uncertainty of the shoreline in both Nigerian sites (Lagos and Pennington) is ~150-200 m at 95% confidence level. In addition, cloud cover in some of sites limited the comparison areas. In Lagos Channel, a visual agreement in shoreline position was observed between the satellite-derived shoreline and the historical low water line (historical map) and the MHWS shoreline (nautical chart). A large change in shoreline position (greater than 1 km) is noticed on the eastern beach in Lagos (Victoria Island beach). This difference is far larger than the estimated positional uncertainty of the shoreline, and is likely indicative of the high coastal erosion rates (i.e., horizontal regression of the shoreline position),consistent with other studies that observed an average erosion rate of 25-30 m/yr (French et al., 1995). In the Escravos study site, the cartographic comparison shows a visual agreement between the charted shoreline and the satellite-derived shoreline along most of the coast. It is important to note that shorelines in the Escravos study site are almost constantly coincident. This can be attributed to the beach slope and the relatively small scale of the chart (1:60,000) used in the comparison. The same issue with the chart scale posed also a challenge in the Pennington study site (chart scale: 1: 350,000). It was possible to notice that the satellite-derived shoreline and the digitized shoreline from the nautical chart agree with each other. It is not clear if the difference in position between the historical map shoreline and the other two shorelines is because of the positional uncertainty of the derived shoreline or if a coastal transgression have occurred (Davis and FitzGerald, 2004), which is uncommon in the region.

A thematic comparison between the satellite-derived shoreline (Figure 3) and the charted shorelines was done by comparing the procedure results to the cartographic symbols on the charts and historical maps. The procedure results were characterized into a hierarchy of characters and attributes based on the IHO S–4 and NOAA Chart No 1 attribute standards. The major classes were man-made and natural, with the latter comprising exposed and vegetated. With the support of reference, current, high-resolution satellite imagery (IKONOS), it was possible to validate that the separation of vegetated areas from exposed areas was successful over the U.S. calibration site and Escravos. The vegetated areas were further separated into two classes over the calibration site and over the over Escravos and Pennington sites. However, the symbols on the charts were not detailed enough to validate the results. Ground truth is required to evaluate the results and determine the threshold between vegetation types and vegetation density. Man-made features (e.g., moles and piers) were identified from the procedure results over the U.S. calibration site and over Lagos. Both the procedure results and the charted shorelines show the abundance of numerous man-made shoreline features, mostly jetties. In addition, the unsupervised classification separated the exposed cover over the calibration site into four classes: mud, rock, wet sand and sand. Three to four exposed land cover classes were also achieved over the Nigerian study sites. Similarly to the vegetation groups, it is difficult to infer the sediment type without ground truth.

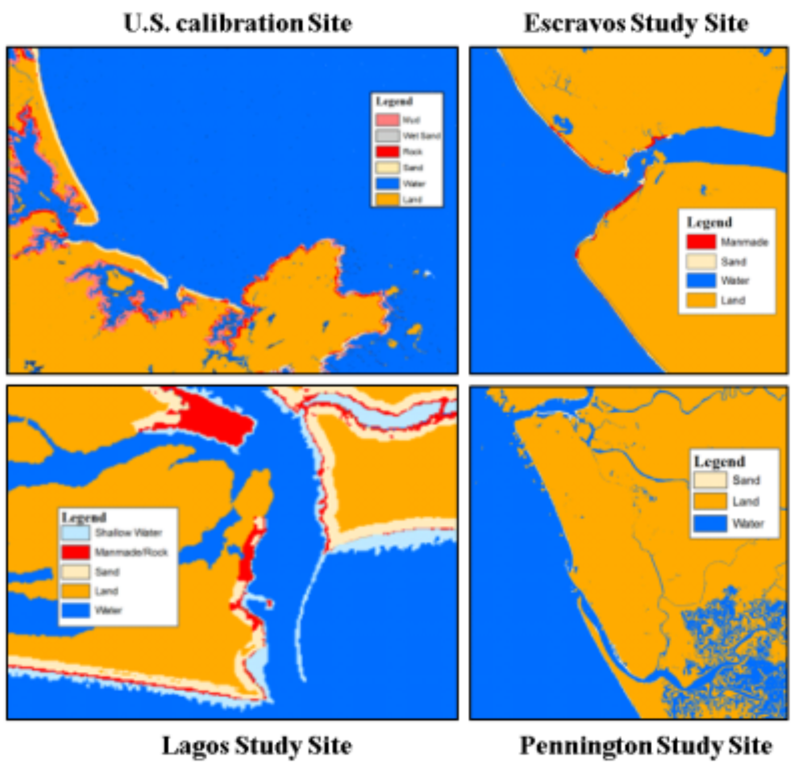

Figure 3. Shoreline characterization results over the U.S. calibration site and the Nigerian study sites.

5 Conclusions

This study set out with the aim of developing a procedure for mapping the Nigerian shoreline into a hierarchy of classes and attributes based on the IHO S–4 attribute standards. The procedure processed Landsat imagery from publically available archives using image processing and spectral analysis. The procedure included a decision tree that: a) classified the images into land and water (level 1), b) characterize the dry land into exposed, vegetated and man-made classes (level 2), c) separated man-made features (sub-pixel features) from the submersed areas (level 2), d) calculated bathymetry for the submersed areas (level 2), and e) assigned an attribute to different segments along the shoreline character (level 3).

The comparison results show a good agreement in shoreline characterization between all three datasets (satellite, chart and map). It was difficult to compare the attribute results of the procedure, due to lack of information about the charted shorelines and lack of ground truth. Challenges that were identified in the procedure included limited number of available satellite images for a given location, cloud cover in the imagery, absence of sufficient data in some nautical charts due to the relatively small scale and printing errors on some historical charts. Also, historical charts were unavailable for some study sites, which limited the comparison results. Although the results provided useful insight, it is necessary to conduct a ground truth survey to further validate them.

To summarize, the characteristics of a shoreline are indicative of potential changes that can occur in the position of that shoreline, as well as its ability to perform certain critical functions and services. Unfortunately, many developing countries are not able to map their shorelines on a frequent basis due to limited resources. This procedure offers a solution to this challenge using free and publicly-available data. Although, the shoreline characterization procedure was developed based on datasets from study sites along Nigerian coastline, the procedure is suitable for mapping coastal areas in other developing regions.

References

Adegoke, J.O., Fageja, M., James, G., Agbaje, G., Ologunorisa, T.E., 2010, An Assessment of Recent Changes in the Niger Delta Coastline Using Satellite Imagery, Journal of Sustainable Development, Vol. 3, No. 4, pp 277-296.

Ibe, A.C., 1988, Coastline Erosion in Nigeria, Ibadan University Printery, 217p.

International Hydrographic Organization (IHO), 1994, Publication S-32, Hydrographic Dictionary, Monaco, 5th edition, 280p.

International Hydrographic Organization (IHO), 2012, Publication S – 4, Regulations of the IHO for International (INT) Charts and Chart Specifications of the IHO, Edition 4.3, Monaco.

Jensen, J.R., 2005, Introductory Digital Image Processing, A Remote Sensing Perspective, 3rd Edt, Pearson Prentice Hall, 526p.

French, G.T., Awosika, L.F., and Ibe, C.E., 1995, Sea-Level Rise and Nigeria: Potential Impacts and Consequences, Journal of Coastal Research, SPECIAL ISSUE NO. 14, pp 224-242

Presenter Biography

Cdr. Olumide Fadahunsi is a hydrographer with the Nigerian Navy Hydrographic Office. A 1996 graduate of the Nigerian Defense Academy, he has served in a variety of naval and hydrographic positions in the Nigerian Navy. In December 2012, Cdr. Olumide Fadahunsi finished his graduate degree from the Center for Coastal and Ocean Mapping at the University of

New Hampshire. He was also pivotal to the implementation of the IMO's International Ship and Port Facility (ISPS) Code in Nigeria.