Developing a Methodology for the Mapping and Characterization of the Nigerian Coastline Using Remote Sensing

Olumide FADAHUNSI, Andrew ARMSTRONG, Shachak PE'ERI, Lee ALEXANDER and Christopher PARRISH, U.S.A

SUMMARY

Coastline delineation is important in maritime boundary determination, as well as for analyzing coastline change rates due to coastal erosion, sea level change, storms, and other causes. Coastline change rate estimates depend on the uncertainty of the current and historical coastlines used in the analysis, which, in turn, depend on the surveying technologies and techniques that were originally used. Current techniques for coastline mapping include photogrammetric delineation using tide-coordinated aerial imagery. However, in many developing countries, the charted coastlines may have been inadequately and inconsistently mapped largely due to inadequate resources. This paper describes the use of an automated technique for coastline mapping and classification that is based on satellite imagery. A spectral analysis using different image bands can be used to define the land/water boundary and characterize the coastal area around the coastline. A first-order uncertainty analysis was also performed. The satellite-derived coastlines were compared to charted coastlines to evaluate the adequacy and consistency of the charted coastlines. The satellite-derived coastlines were also compared to coastlines derived from historical maps to assess changes and change rates. The results of the coastline uncertainty analysis were then used to compute propagated uncertainties in coastline change rate estimates and to gain greater insight into actual changes. The procedure was developed in a GIS environment using study sites along the Nigerian coastline. However, this procedure can be applied to other poorly charted/mapped coastal areas as well.

Key words: Coastline delineation, Remote Sensing

1. INTRODUCTION

The physical characteristics of a shoreline provide an indication of the processes that formed it, such as wind, waves, tides, currents, and sedimentation. Many areas of the world are experiencing coastal erosion, while, at the same time, human activities, such as coastal development and engineering, are leading to an increase in manmade shorelines. Following the growing diversity of shorelines, natural and manmade, cartographic attribution schemes have been developed for shoreline classification. Examples of such attribution schemes are the S-57 standards of the International Hydrographic Organization (IHO) and the Coastal Cartographic

Object Attribute Source Table (C-Coast) of the National Oceanic and Atmospheric Administration (NOAA).

Shoreline type can be used as an indicator of potential change in the shoreline's position. For example, sandy shorelines are susceptible to natural processes (*e.g.*, storms and tsunamis) and human activities (*e.g.*, dredging and infrastructure development) that may cause accretion or erosion of the shoreline. In addition the shoreline character can help to describe the existing hydrological, chemical, physical and biological conditions of the shoreline. These conditions are indicative of the overall coastal ecosystem health.

The challenges of shoreline mapping include the costs of acquiring current survey data over the coastal area. As a result, in many developing countries, the shoreline has not been consistently mapped. Most of the shoreline data is based on surveys of opportunity. The variety of methods used for this mapping, and the large time differences between the surveys (on the order of years) could result in inaccuracies in shoreline data. Common practices utilize aerial imagery and field surveying for mapping the shoreline. However, these methods involve considerable investments in human and material resources.

This study presents the development of shoreline characterization procedure using satellite remote sensing technology. The study goal is to produce a complete, consistent and continuous mapping using publicly available data (LANDSAT satellite imagery) in a GIS environment (ArcMap10). 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 evaluation. The satellite-derived shorelines were also compared to shorelines from historical maps to monitor any changes that occurred between the survey periods of the source data. The procedure was developed based on study sites along the Nigerian coastline.

2. SHORELINE CHARACTERIZATION

In many charting organizations, shoreline is divided into three main classes: 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 anchoring). 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.

2.1. Natural shorelines

Natural shorelines are typically separated based on their coverage. A vegetated coastline is one contains rooted vascular plants that are a persistent feature of the coastal landscape (Schwartz,

2005). They can include sea-grass beds, brush, mangroves and trees. The type of vegetation depends on the climate, sedimentary deposits, and wave and tidal energy regimes in the coastal area. In certain cases, the vegetation is such that it difficult to define the land/water interface as the shoreline based on remote sensing (aerial or satellite). In such situations, the outer limit of the vegetation area is selected as the "apparent shoreline".

The exposed shoreline is any natural shoreline that is bare of vegetation in the immediate vicinity of the land/water interface. Exposed shoreline are characterized by several parameters: sediment coverage (*e.g.*, sandy, clay, rocky) or rocky outcrop, morphology and slope of the coastal areas around the shoreline (*e.g.*, flat, slope and cliffs) and mineral composition (*e.g.*, limestone and volcanic).

Man-made shorelines

Man-made shorelines are similar to natural exposed shorelines, as they do not have vegetation cover. They can be composed from either natural resources (e.g., sand and rocks) or artificial material (e.g., concrete and asphalt). They typically have a well-define geometrical shape with a sharp transition between land and water resulting in very steep and at times almost vertical slopes.

3. METHODOLOGY AND PRELIMINARY RESULTS

3.1. Study sites

Three study sites for the development of the shoreline characterization procedure were selected along the Nigerian shoreline. The shoreline of Nigeria extends for about 800 km and lies in the in the Gulf of Guinea (GoG), west coast of Africa. About half of the shoreline is in the Niger Delta, and the predominant current in the area is the Guinea current, which is a continuation of the southeast branch of the Canary current (Nicolas and Williams, 2008). The tides along the Nigerian coast are semidiurnal with range varying from about 1 m on the western coast to approximately 3 m on the east (Sexton and Murday, 1994). Wave heights that exceed 1m are common on the western beaches and the exposed delta front, particularly during the rainy season (May – October) when long period waves are common. The dominant wind around Nigeria's shoreline is southwesterly. The southwesterly wind and the hydrographic regime along the coast has a pronounced effect on its morphology as it affects the orientation of coastal sand deposits and longshore transport directions (Sexton and Murday, 1994). The Nigerian shoreline is characterized by a mixture of sand which is predominant on the western boundary and mud deposits. The vegetation along the eastern coast of Nigeria varies with mangroves common in the Niger Delta while vegetation is sparse on the western coast.

3.2. GIS environment

The shoreline mapping and characterization procedure was developed in a GIS environment (*ArcMap10*). Nautical charts and topographic maps from different time periods covering the same area were scanned and georeferenced to a WGS84 geographic horizontal datum. After loading all charts and maps into the project, shorelines were manually delineated and the shoreline character defined on the chart symbols and the sailing directions (IHO S-57 and NOAA C-COAST).

3.3. Satellite imagery

LANDSAT satellite images were downloaded from the U.S. Geological Survey's website. The satellite images were georeferenced and contained only six bands (Table 1) in a TIF format. The shoreline was delineated using the infrared band to separate the dry land from the water. To facilitate adequate characterization of the shore, a 90-m buffer zone was created around the shoreline. The buffer zone includes two areas: the immediate landward (above the waterline), and seaward (below the waterline) areas. Shoreline characterization was conducted for both areas in the buffer zone using spectral analysis. Six LANDSAT channels (Blue, Green, Red and all Infrared bands less the thermal Infrared) were used for the landward buffer zone, while three channels (Blue, Green and Red) were used for the seaward buffer zone. Based on the results, the shoreline was classified as natural or man-made.

Band	Wavelength (micrometers)	Resolution (m)
1	0.45-0.52	30
2	0.52-0.60	30
3	0.63-0.69	30
4	0.77-0.90	30
5	1.55-1.75	30
7	2.09-2.35	30

Table 1 - Band Designations for LANDSAT 7 ETM+

3.4. Preliminary results

Three shoreline-character classes were produced from the LANDSAT imagery: natural vegetated, natural exposed, and man-made. These classes were arrived at using a combination of the spectral signature of the land cover type, slope of the coastline and how well defined it was geometrically. This process involved the use of various algorithms as indicated in the decision tree shown in Figure 1. The preliminary classification results were compared to the nautical charts and topographic maps on a thematic level. The thematic comparison results will help identify sensor limitations and accuracy. The results were also compared cartographically. The cartographic comparison of the results and the error analysis will attempt to decouple real shoreline changes from errors derived in the shoreline mapping procedure.

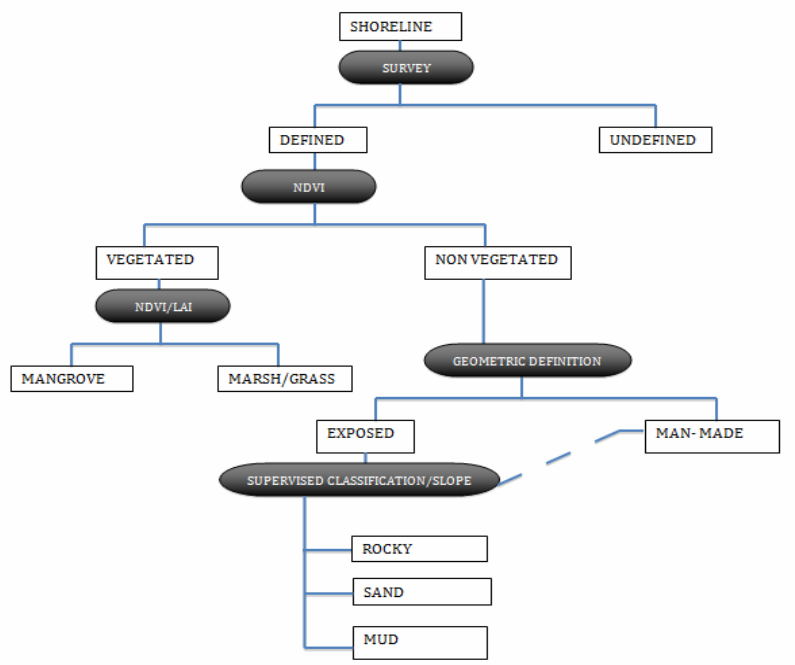

Figure 1 - Decision Tree for Characterizing Coastline.

4. CONCLUSION

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 paper offers a solution to this challenge using free and publicly-available data.

The characteristic of a shoreline can be separated into three broad groups; natural, man-made and undefined. Natural shorelines can be sub divided into vegetated and exposed shorelines with the major difference being the presence or absence of vegetation. Man-made shorelines are bare of vegetation and can be composed of natural or artificial materials. They sometimes have a well defined geometry and usually have steep slopes.

This study was conducted on three sites off the coast of Nigeria. It was conducted in a GIS environment using historical charts, current charts and 5 channels of the LANDSAT imagery. First, the shoreline was delineated using the Infrared band and thereafter, a spectral analysis of a 90 m buffer zone was done to separate it into various land cover types.

Preliminary results revealed three shoreline character classes. This was arrived at using a decision tree that involved the use of different algorithms, geometry and slope. The results were compared to historical and current charts thematically and cartographically. The thematic

comparison revealed the limitations and accuracy of the sensor while the cartographic comparison in conjunction with an error analysis attempted to decouple real shoreline changes from errors in the mapping procedure.

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BIOGRAPHICAL NOTES

Cdr. Olumide Fadahunsi is a hydrographer with the Nigerian Navy. He has served in a variety of hydrographic positions and participated in the implementation of the IMO's International Ship and Port Facility (ISPS) Code in Nigeria. He is currently a graduate student at the Center for Coastal and Ocean Mapping.

CONTACTS

Olumide Fadahunsi
Center for Coastal and Ocean Mapping
24 Colovos Rd
Durham, NH
U.S.A
Tel: 1-202-650-9327
Email: jide.fadahunsi@gmail.com