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ISPRS Journal of Photogrammetry & Remote Sensing 63 (2008) 543–558
PHOTOGRAMMETRY & REMOTE SENSING
www.elsevier.com/locate/isprsjprs

Detection, measurement and prediction of shoreline recession in Accra, Ghana

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Received 30 May 2007; received in revised form 31 March 2008; accepted 5 April 2008
Available online 27 May 2008

Abstract

Coastal mapping, using various data capture and feature extraction techniques, has furthered understanding of trends in shoreline evolution by allowing calculation of accurate historic rates of change that subsequently enable the prediction of future shoreline positions through different modelling procedures. The results have helped influence coastal policy formulation and promoted the development of sustainable management practices in coastal regions throughout the developed world. However, sustainable coastal management is rarely practiced in developing countries, one of the fundamental reasons for this being a general lack of reliable and accurate historic data on shoreline position. Previous studies on the Ghanaian coastal region of Accra, where accurate and reliable geospatial data for analysis is scarce, have reported erosion rates of anything between two and eight metres per year. This high level of inconsistency in reported rates has hindered effective and sustainable coastal management. The research reported in this paper addresses this issue, using mapping data from 1904, 1974, 1996 and 2002 to estimate, by linear regression, shoreline recession in the Accra region. Predictions for the next 250 yr were then undertaken using a variety of techniques ranging from a process-based numerical model, SCAPE, to geometric approaches including historical trend analysis, the modified Bruun model and Sunamura's shore platform model. Uncertainties in the various input data were accounted for, including historic recession rates, rock strength, sediment content and, importantly, future sea-level rise under different climate change scenarios. The mean historic rate of erosion in the Accra region was found to be 1.13 m/yr(±0.17 m/yr), significantly less than previously reported, though still very high. Subsequent predictions were used to identify a series of significant economic, ecological and social features at risk, and to estimate when they will most likely be lost to erosion if left unprotected. The case study illustrates that, provided suitable predictive models are selected and the uncertainties involved in working with limited data sets are dealt with appropriately, it is possible to provide statistical information in support of sustainable coastal management for developing countries in the face of a changing climate.

Keywords: Shoreline evolution; Coastline; Sea-level rise; Erosion prediction

1. Introduction

Shorelines, defined as the interface between sea and land (Boak and Turner, 2005), tend to retreat, with over 70% of the world's beaches experiencing coastal erosion (Bird, 1996). This presents a serious hazard to many coastal regions, where it is estimated that about 25% of productivity occurs and 60% of the population lives (Al-Tahir and Ali, 2004). Climate change, particularly accelerated sea-level rise, is expected to exacerbate this problem (IPCC, 2007)

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0924-2716/$ - see front matter
doi:10.1016/j.isprsjprs.2008.04.001

meaning that sensible management strategies are increasingly required to deal with the risks arising from coastal erosion. In addition to present day monitoring campaigns (e.g. Miller et al. (2007)), coastal management relies on information about historic shoreline location and movement, and on predictions of future change. There is increasing recognition that such quantified geomorphic understanding should be built at large scales, e.g. tens of kilometres and over years to centuries, in order to plan sustainable and spatially integrated measures. Ground-based surveys of dynamic (particularly eroding) large scale landscapes are inherently problematic and often prohibitively expensive (Mills et al., 2005). For this reason much of the world's coastline morphology has not been properly quantified, particularly in developing countries. Remote sensing, however, allows the current position of coastlines to be rapidly established at relatively low cost. Future repeated observations will, over time, allow detailed quantification of shoreline change. In the meantime coastal morphology may be quantified by coupling remotely sensed data with information on historic coastline position from archived sources.

Accurate mapping of instantaneous shoreline position has, due to the coast's dynamic nature, always been associated with significant uncertainty. This situation arises because at any particular time the shoreline position is influenced by the short-term effects of tide and long term relative sea level rise, as well as the cross-shore and alongshore littoral sediment movement. This affects the accuracy of computed historic rates of change and therefore the reliability of any predicted future shoreline positions. The science of shoreline mapping has experienced significant changes over the past 70 yr (Crowell, 2006), as techniques progressed towards automation with advances in technology and the need to reduce uncertainty. Although the changes have resulted in improvement in coastal data processing and storage capabilities, the frequent change in technology has prevented the emergence of a standard method of shoreline mapping (Moore, 2000), as the various methods have their unique capabilities and shortcomings. Despite recent research into integrated methods for coastal monitoring (e.g. Mills et al. (2003), Miller et al. (2007) and Thieler and Danforth (1994a)) point out that no independent method addresses the entire range of cartographic and photogrammetric techniques required for accurate coastal mapping, and therefore the application of existing methods to many typical shoreline mapping problems is limited. Use of any particular method is influenced by the data sources and resources available.

Modern data sources, which have come about as a result of recent developments in remote sensing technologies using space, air and land based techniques, present the shoreline in a data format ripe for analysis in GIS. Archived data sources, usually hardcopy maps and aerial photographs, provide historic records not available from modern sources and can be digitally exploited in GIS following either manual digitising or scanning. These data sources provide a good database for compilation of shoreline positional information that enables historic rates of change to be calculated. Prior to the widespread adoption of GIS technology by coastal scientists, reliable and defensible shoreline change rates were often illusive targets (Zuzek et al., 2003) due to the poor understanding of spatial and temporal influences on shoreline evolution. Shoreline rate of change statistics represent a cumulative summary of the processes that have affected the coast (Dolan et al., 1991). The variability of such statistics depends significantly on the methodology used to derive them (Dolan et al., 1991; Genz et al., 2007). Normally linear regression is used to calculate shoreline rate of change, although numerous other statistical methods have been used, including end point rates, average of rates, jackknife and weighted linear regression.

Historic shoreline rates of change of complex and dynamic large-scale coastal systems cannot be assumed to continue into the future (Lakhan, 2005). It is also evident that recent acceleration in sea-level rise due to global warming (Rahmstorf et al., 2007), and the expectation that this will continue for centuries (IPCC, 2007), mean that future recession will, generally, be greater than it has been in the recent past. Models capable of accounting for such accelerated sea-level rise are still relatively undeveloped (Bray and Hooke, 1997), although significant recent improvements have been made (e.g. Walkden and Hall (2005) and Dickson et al. (2007)). All of the available methods require reliable and accurate information on historic shoreline behaviour, and this is made difficult and uncertain if observational data is sparse and short term. Crowell et al. (1993) argued that such data sets for obtaining consistent long term rates of change should cover at least 60–80 yr in order to span short term storm events and natural decadal scale variability. An additional problem is that many shorelines have been engineered in ways that mask natural behaviour. Assessing and predicting coastal change is therefore a particular challenge in regions where shoreline data are scarce, especially in developing countries. According to Bird (1985), reliable shoreline surveys exist in such places only for the past few decades, usually the period for