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Nile Delta exhibited a spatial reversal in the rates of shoreline retreat on the Rosetta promontory comparing pre- and post-beach protection

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ABSTRACT

The coastline of the Nile Delta experienced accelerated erosion since the construction of the Aswan High Dam in 1964 and, consequently, the entrapment of a large amount of river sediments behind it. The coastline of the Rosetta promontory showed the highest erosion in the Delta with an average retreat rate of 137.4 m $year^{-1}$. In 1991, in an effort to mitigate sediment loss, a 4.85 km long seawall was built on the outer margin of the promontory. For additional beach protection, 15 groins were constructed along the eastern and western sides of the seawall in 2003 and 2005. To quantify erosion and accretion patterns along the Rosetta promontory, 11 Landsat images acquired at unequal intervals during a 40 year time span (1972 and 2012) were analyzed. The positions of shorelines were automatically extracted from satellite imagery and compared with three very high resolution QuickBird and WorldView2 images for data validation. Analysis of the rates of shoreline change revealed that the construction of the seawall was largely successful in halting the recession along the tip of the promontory, which lost 10.8 km^2 prior to coastal protection. Conversely, the construction of the 15 groins has negatively affected the coastal morphology of the promontory and caused a reversal from accretion to fast erosion along the promontory leeside, where some segments of the shoreline have undergone as much as 30.8 m $year^{-1}$ of erosion. Without hard structures, the tip of the Rosetta promontory would have retreated 2.3 km by 2013 and lost 7.2 km^2 of land. About 10% of this land is deltaic fertile cultivated farms. Moreover, without additional protection the sides of the promontory will lose about 1.3 km^2 of land and the coastline would recede at an average rate of 200 m by 2020. Unless action is taken, coastal erosion, enhanced by rising sea level, will steadily eat away the Nile Delta at an alarming rate. The successful demonstration of the advocated procedures in this study could be adopted, with appropriate modifications, for other deltas worldwide.

1. Introduction

Shorelines are very dynamic geomorphic systems where continuous changes occur at different spatial and temporal scales. Shoreline changes may occur in response to smaller-scale (short-term), large-scale (long-term) and medium-scale (intermediate-term) events. In the short-term scale, coastal changes are mostly related to fluctuations in wave action, storms, tides and winds, whereas, on the long-term scale (centuries and millennia) coastal changes are associated with glaciation, relative oscillations of sea level, mainly driven by climatic changes, and tectonic activities that cause coastal land subsidence or emergence (Cowell and Thom, 1994; Del Río et al., 2013). On the intermediate-term scale (decades), however, factors inducing coastline changes are more complex and interrelated and mostly related to anthropogenic causes (Del Río et al., 2013). At such scale shorelines often change quite rapidly in both space and time. In recent times, human activity has intensely modified the natural evolution of coastal zones and has become the most important controlling factor (Kapsimalis et al., 2005; Stefano et al., 2013). Such activities along the coast and within the river basin usually intensify coastal erosion and risk coastal inhabitants. Gaining knowledge on coastal retreat at the intermediate-term scale would enhance our capability to manage risks affecting such coastal areas.

Coastal retreat is defined as the landward displacement of a shoreline because of marine erosion or flooding (Bird, 1993). Coastal retreat generally occurs when the coastal erosional processes overcome the sediment supply (Stefano et al., 2013). The reduction in sediment supply, as a result of man-made work across rivers, appears to be the key factor in controlling shoreline retreat as it reduces the riverine sediment fluxes and alter the normal sediment dispersal at the river mouths (Stefano et al., 2013). Today, many large rivers in the world are experiencing decreased sediment loads due to dam induced sediment starvation. Sediment starvation usually affects downstream river deltas by causing bank erosion and increased rates of land loss along the delta shorelines by reducing sediment replenishment. In fact, river deltas, such as the Nile (Egypt), Colorado (Mexico), Indus (Pakistan), Ibro (Spain); Krishna (India), and Yellow (China) deltas have all experienced

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sediment reductions of 90% or more (Ibanez et al., 1996) mainly because of dams construction upriver.

Over the last decades, coastal retreat has been a problem of increasing magnitude along the shoreline of the Nile Delta. The coastal erosion has been greatest, in particular, on the two Nile promontories, Rosetta and Damietta (White and El-Asmar, 1999; Frihy et al., 2003; Frihy and Lawrence, 2004; Ghoneim, 2009; Hereher, 2011) due to the construction of irrigation control structures such as barrages and large hydropower dams along the Nile River including the Aswan High Dam. This study focuses on the Rosetta promontory and its vicinity which covers an area of 228 km^2 (Fig. 1). The gradual rise in sea level, due to global warming, is expected to worsen coastal erosion in the area as higher water levels allow wave and current erosion processes to act farther up on the beach, which helps waves break closer to shore, causing increased erosion (Rabbani et al., 2010). A relative sea level rise (SLR) of 4.9 mm year^{-1} was recorded across the Rosetta area as a result of land subsidence due to natural compaction and dewatering of Holocene deltaic sediments (Frihy et al., 2010). A much higher coastal submergence rate of 5.4 mm year^{-1}, as a result of combined SLR and land subsidence by compaction, was recorded in the northwestern sector of the Nile Delta, where the Rosetta promontory is situated (Stanley and Corwin, 2013). Standing only a few meters above sea level, the coastal zone of the Nile delta is susceptible to inundation and increased shoreline erosion.

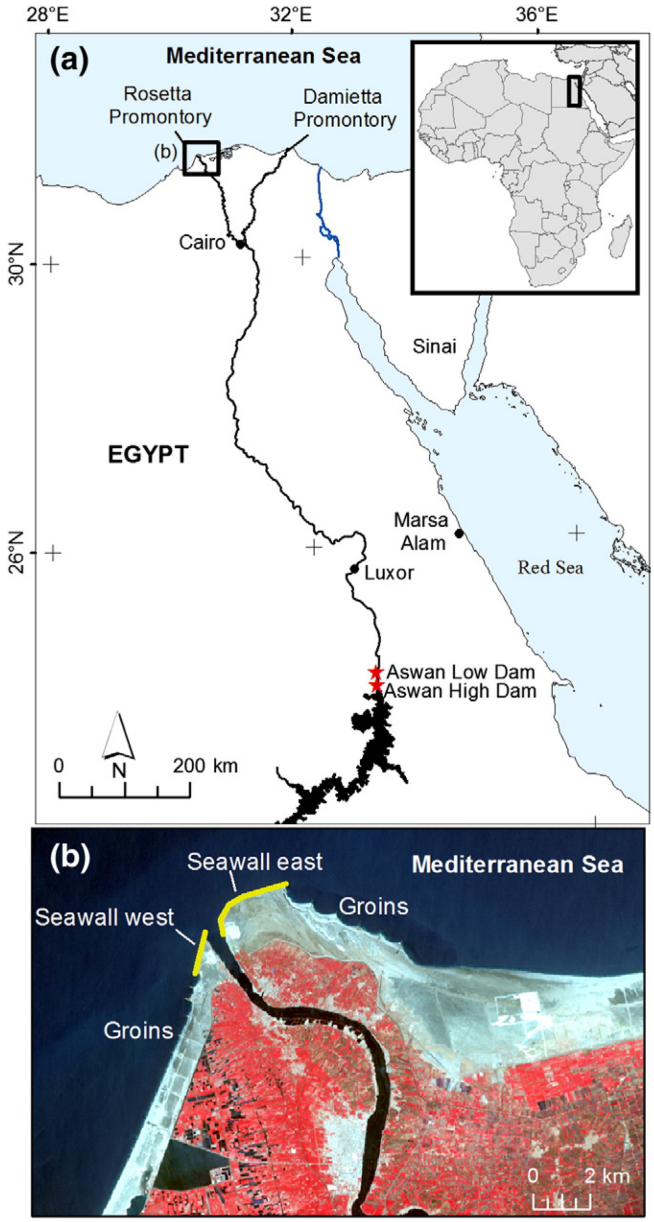

Fig. 1. Location of the study area. (a) The Nile Valley and the position of the Aswan High Dam, which causes a reduction in sediment supply to the lower delta plain. The box to the northwest of Cairo represents the area shown in (b). (b) Landsat-8 color composite (bands, 5, 4 and 3) of the Rosetta promontory showing sites of constructed seawall and groins.

Remote sensing and GIS are very useful technology for detecting and monitoring shoreline change (Ghoneim, 2009). The synoptic capability of remote sensing provides a useful reconnaissance tool to target more detailed field surveys on areas of accelerating change (White and El-Asmar, 1999). Recent analysis of satellite imagery reveals that, even with the protected measures emplaced along the Rosetta promontory, coastal erosion is steadily impacting its shoreline at an astonishing rate (Dewidar and Frihy, 2007). This paper expands on this work to gain a better understanding of the erosion/accretion process and rates of shoreline retreat along the Rosetta promontory. The main objectives here are:

1. Mapping the shoreline positions of the Rosetta promontory over a 40 year time span (1972 and 2012) in an attempt to spatially and quantitatively estimate the coastal retreating rates pre- and post-beach protection.
2. Examine the efficiency of using the moderate resolution Landsat imagery in mapping shorelines and estimating rates of coastal change through a comparative analysis with very high resolutions (VHR) multispectral imagery.
3. Predict future coastline positions, based on short-term shoreline changes, and identifies areas and major types of land use/cover that will be susceptible to coastal erosion.

2. General coastal process

The Nile River Delta spans approximately 250 km of Egypt's shoreline and makes up a portion of the most fertile land in Egypt. Today, this delta is one of the most heavily populated and intensely cultivated areas on Earth. Despite covering only 2.5% of Egypt's total land area, the Nile Delta sustains about two thirds of the national population (~80.72 million in 2012; World Bank, 2012) and produces nearly 60% of Egypt's food supply (Shenker, 2009). Accordingly, Egypt relies unconditionally on the Nile Delta for food security.

The former Nile Delta had seven main branches (distributaries) to the Mediterranean Sea. At that time the delta was a wave-dominated, smooth, and arcuate type delta (Smith and Abdel-Kader, 1988). Many of these branches were abandoned over time and finally the Nile discharge was confined to two branches; the Rosetta and Damietta branches. The Rosetta branch is believed to have been formed during 500–1000 AD, when water from two of the seven preexisting branches (known as Canopic and Sebennitic) was diverted into one river canal (NESCO/UNDP, 1978). Since that time the Nile Delta changed to river-dominated sedimentation type delta (NESCO/UNDP, 1978; Smith and Abdel-Kader, 1988).

The coast of the Nile Delta is typically wave- and current-dominated (Manohar, 1981). Wave action along the Nile Delta is seasonal and is dependent on the changing wind systems over the eastern Mediterranean Sea (Dewidar and Frihy, 2007). The coastal processes influencing the shoreline of the Rosetta promontory, including winds, waves and currents actions, have been discussed extensively by previous studies (Khafagy and Manohar, 1979; Manohar, 1981; Frihy, 1988; Fanos, 1995; Dewidar and Frihy, 2007). Along this promontory, two main wave directions can be distinguished and are believed to be the predominant causes of the morphological changes in the area (Manohar, 1981; Dewidar and Frihy, 2007). The first wave direction, the most dominant, is from the northwest (NW) and is responsible for generating