DISAPPEARING DELTAIC BEACHES: CLIMATE CHANGE OR HUMAN INTERVENTION? THE CASE STUDY OF THE ALFIOS RIVER DELTA

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Introduction

The evolution of deltaic beaches is the result of the interaction between riverine sediment fluxes, nearshore hydrodynamics and human interference. During the last century, the construction of 17 large hydroelectric dams in Greece has caused a significant retention of sediments within the reservoirs and a dramatic reduction of the sediment supply (Poulos and Collins, 2002), which has stopped the progradation of delta fronts and induced coastal erosion, which is more pronounced at the river mouth areas and the adjacent deltaic coasts. This situation has been aggravated by channelization of the lower route of most major rivers and the extensive abstraction of sand and gravel from the river beds.

Climate change can also lead to severe deltaic beach erosion, through a significant reduction in the number of flood events, leading to enhanced subsidence of the deltaic plains and retreat of the shoreline or through increased storminess and alteration of the nearshore hydrodynamic conditions and sediment transport paths.

The present work investigates the relative importance of the above processes for the documented shoreline retreat of the Alfios river delta during the last 70 years (Figure 1).

Two dams have been built in the Alfios river basin: The Ladonas hydroelectric gravity, which went into operation in 1955, cutting off an upstream area of approximately 900 km^2, corresponding to 25% of the catchment area of the Alfios river, and the Flokas dam, which became operational in 1967, is only 5.5 km away from the coastline and, having behind it 97% of the Alfios catchment area, has drastically reduced the sediments delivered to the coastline, by cutting off totally the bedload and most of the suspended sediment transport. However, the two flush gates of the Flokas dam, which are usually opened after heavy rainfall and during extreme river discharge events, sporadically flush downstream part of the sediments deposited behind the dam. These sediment quantities may partly compensate for the abstraction of aggregates along the lower route of the R. Alfios, estimated at $11.5 \cdot 10^6$ m^3, according to Manariotis and Yannopoulos (2004).

Methodology

The interannual (long period) changes of the coastline position were studied with the use of a series of aerial photographs of the Hellenic Army Geographical Service (HAGS) taken in 1945 (scale

1:42000), 1960 (1:30000), 1972 (1:15000), 1984 (1:15000), 1996 (1:15000), one satellite image (2009) and four Google Earth satellite images (2003, 2010, 2012 and 2013). The aerial photographs were digitized by scanning at 1200dpi, radiometrically corrected, orthorectified with the use of an Intergraph Z/I Imaging photogrammetric station, georeferenced with the use of ArcGIS, and the deltaic shoreline positions were extracted.

Changes in the wind regime of the broader region of the NE Ionian Sea were investigated using the wind records (1961-2010) of the Hellenic Meteorological Service at Andravida. The nearshore wave conditions and sediment transport patterns were hindcasted using the equations of CERC (1984).

Results and Discussion

Between 1945 and 2014, the deltaic shoreline of the Alfios River has retreated more than 450 m on the N side of the mouth (profile N1) and more than 250 m on the S side (profile S1) with the shoreline retreat decreasing with distance from the mouth to 200 and 156 m at profiles N2 and S2, respectively.

The largest retreat occurred from 1945 to 1960, reaching 160 m on the north and 100 m on the south side of the river mouth, and the northern part of the delta continued to retreat by a further 100 m during the period 1960-1972, as a result of the operation of the two dams. The subsequent period (1972-1984) is characterized by a reduced rate of coastline retreat, while the delta was tending towards a new dynamic equilibrium under the reduced riverine sediment fluxes and incorporating the longshore sediment advection (mainly from the south).

During the period 1984-1996 the coastline retreat is rather intensive again. This extensive retreat is attributed, partly, to the abstraction of sand and gravel from the lower reaches of the Alfios river channel (the legal abstraction of riverine aggregates stopped in 1995). Subsequently, the Alfios river mouth area retreats with much lower rates (2.9-4.3 m/a), indicating that, although the coastal deltaic system seems to tend gradually towards a new dynamic state of equilibrium, the sediment deficit sustains these lower erosion rates. However an increased retreat rate is observed from 2003 to present in the area of profile S2.

Analysis of the wind records of the meteorological station at Andravida revealed a significant change in the frequency and direction of severe storms with wind speeds exceeding 40 knots (Table 3). The number of S, SW and W storms, which induce a northward sediment transport, has decreased from 4 storms in the decade 1971-1980 to one in the next two decades and none in the decade 2001-2010. At the same time, the number of NW and N and NE storms has increased from none in the decade 1961-1970 to 2 storms in 1971-1980 and 3 storms in the decade 1981-1990, to decrease again to none in 1991-2000 and 1 in 2001-2010. These changes in severe storm activity and the subsequent changes in longshore sediment transport correlate very well with the observed shoreline displacements. Further research is underway to investigate whether the above changes in severe storm direction, frequency and intensity are due to climate change or to a decadal variability in the wind regime of the Ionian Sea, that may be related to the North Atlantic Oscillation (NAO) and the Mediterranean Oscillation (MO).

Finally, another process that may be contributing to the aforementioned deltaic retreat is the relative sea level rise induced by climate change, which, according to the IPCC has started to become significant during the 1980s, when the rate of sea level rise exceeded 3 mm/a; this value is significantly higher than the steady rate of 0.9 mm/a during the last 5000 years, estimated for the central Aegean Sea by Poulos et al. (2009).

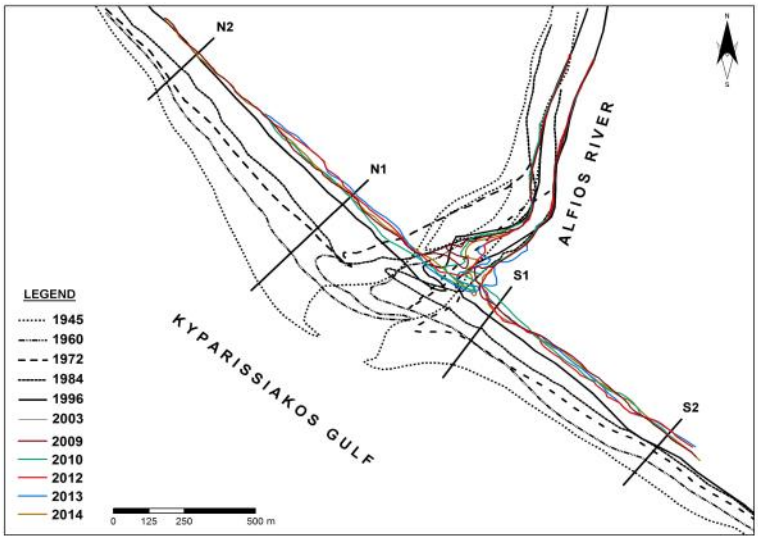

Figure 1: Changes of the deltaic shoreline of the Alfios River from 1945 to 2014 and the locations of four shore-normal profiles (N1, N2, S1, S2).

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