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The consequences of a future eustatic sea-level rise on the deltaic coasts of Inner Thermaikos Gulf (Aegean Sea) and Kyparissiakos Gulf (Ionian Sea), Greece

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ABSTRACT

The spatial consequences of future sea-level rise upon the coastal plains of Greece are examined; in particular, those related to the formation and evolution of the river-deltas. For this reason, the fluvially-dominated deltas of the Axios and Aliakmon rivers of Inner Thermaikos Gulf (NW Aegean Sea) together with the wave-dominated delta of the Alfios River (Kyparissiakos Gulf, Ionian Sea), are investigated. Coastal changes are quantified due to the combined effects of the processes of inundation, because of the increased sea level, and subsequent coastal erosion, due to increased exposure to wave action. Predictions of responses to future sea-level rise, of 0.5 to 1 m, are made. In the case of the deltaic coast of the Alfios, exposed to high waves and protected by dune fields, shoreline retreat of up to 700 m is predicted. The low-lying bird-foot type deltas of the Axios and Aliakmon are expected to retreat by more than 2 km. Furthermore, coastline retreat in the case of Alfios is related primarily to the process of shore zone erosion; in the case of the Axios and Aliakmon, it is related to the process of inundation.

1. Introduction

The vulnerability of the Mediterranean coastal zone to sea-level rise has already been investigated (e.g. Jeftic et al., 1992), whilst Nicholls and Hoozemans (1996), using the Global Vulnerability Analysis (GVA), have shown that the southern part of the Mediterranean coast is more vulnerable than its northern part. Moreover, it has been recognised that deltaic zones are the most vulnerable sectors to sea-level rise. Of course, the spatial and socio-economic consequences of a potential sea-level rise upon deltaic coasts depend also upon the rate of local subsidence, riverine sediment supply, human response, etc. Undoubtedly, any sea-level rise, apart from the inundation caused, will modify the nearshore topography, by moving the nearshore zone shorewards; this will cause further changes to wave-induced circulation patterns, which are related to sediment transport processes (Zhang et al., 2004). Therefore, the impact of sea-level rise on lowland coasts is most likely associated with two different mechanisms: (i) inundation that is related mostly to sub-aerial topography and to the rate of sea-level rise; and (ii) erosion, which is controlled by shore zone morphology and nearshore hydrodynamics. Especially for long-term coastal evolution, the rate of sea-level change has been recognised as one of the most important driving factors among marine processes (e.g. Sánchez-Arcilla et al., 2000).

Over the last decades, several studies have been undertaken for the larger Mediterranean deltas, including vulnerability assessment due to sea-level rise, as in the case of R. Nile (Milliman et al., 1989), R. Rhone (Suanez and Provansal, 1996), R. Ebro (Sánchez-Arcilla et al., 1998) and the northern Adriatic Italian coast, including the R. Po delta (Colantoni et al., 1997). In addition, Maroukian (1989) has studied the consequences of sea-level rise along the Greek coast. Further, Gaki-Papanastasiou et al. (1997) have found that, in the case of four Greek river deltas, some 12% of their coastal area will be submerged if sea level rises by 0.5 m. In addition, several conceptual models have been developed and applied, aiming to predict shoreline response to sea-level change e.g. Bruun (1954), Swift (1976), Stive and De Vriend (1995), Davidson-Arnott (2005).

The purpose of the present study is to investigate the spatial consequences of future sea-level rise on two deltaic coasts of Greece, according to the most widely-accepted eustatic scenario, provided by the Intergovernmental Panel for Climatic Change (IPCC); this predicts a sea-level rise from 49 cm (IPPC, 1996) up to 62 cm (IPCC, 2001), due to global warming by 3 °C within the next 100 years. The coastal areas investigated are: (i) the inner Thermaikos Gulf (NW Aegean), where the fluvially-dominated deltas of Rivers Axios, Aliakmon and Gallikos have been formed; and (ii) the northern part of Kyparissiakos Gulf (Ionian Sea) which hosts the wave-dominated deltaic coast of the R. Alfios. Moreover, the present contribution not only estimates the deltaic area that would be inundated, due to sea-level rise, but also provides an assessment of a further coastline retreat induced by coastal erosion, due to the increase in nearshore water depths.

2. The study areas

The evolution of the deltaic coasts of inner Thermaikos Gulf and Kyparissiakos Gulf, which are formed in an essentially tideless

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(<20 cm) environment (Tsimplis, 1994), as with the remainder of the eastern Mediterranean deltas, depends primarily upon interaction between the fluvial (water/sediment fluxes) and the marine (mostly wave activity) processes; the latter are enhanced in the case of wave set-up conditions, which can reach 1 m in the semi-enclosed Thermaikos Gulf and 0.4 m in the open Kyparissiakos Gulf (Ghionis, 2001; Poulos et al., 2002). The River Axios discharges into the shallow inner Thermaikos Gulf, forming a fluvially-dominated delta, which faces south (Fig. 1). The present-day river channel is artificial, with flood protection levees on either side. The whole delta area is flat, with elevations of less than 1 m above m.s.l. The lower delta is covered by perennial or intermittent marshes and swamps, while the rest of the delta area is wet ground and agricultural land, drained by an extensive channel network. The NE and NW parts of the delta have some low coastal protection levees. During the last decades the deltaic coast has retreated due to reduced sediment supply (Kapsimalis et al., 2005). The Aliakmon River also forms a fluvially-dominated delta, located to the SW of the Axios delta and facing SE. Two older mouths exist to the NE of the present-day mouth. The lower delta is a flat area with elevations of less than 0.5 m above m.s.l., covered by perennial or intermittent marshes and swamps. The whole delta area has elevations of less than 2 m above m.s.l. and the delta front is retreating, due to sediment deprivation following the construction of a series of hydroelectric dams (Poulos et al., 2002). Between the deltas of the Axios and Aliakmon rivers lies the Loudias–Aliakmon deltaic plain. This area used to enclose the old delta of the Loudias River, lowland areas covered by perennial and intermittent marshes and swamps, together with a coastal lagoon that was used for aquaculture. Most of this area has been reclaimed, drained by an extensive channel network and is used for agriculture. Elevations throughout this area do not exceed 1 m above m.s.l.

The Alfios is the largest river of SW Greece and discharges into Kyparissiakos Gulf, forming a cuspate delta. Its mouth is exposed to high-energy waves coming from S, SW and W; mean annual average wave heights and periods are in the order of 1 m and 3 s, respectively, with maximum values in excess of 6 m and 12 s. The sediments of the near-mouth bottom surface are sandy (from gS to S, according to Folk's, 1974 classification). Since the construction of dams (1954 and 1988), the deltaic shoreline of Alfios has retreated at an average rate of 8 m/year, which has produced a maximum shoreline recession of 340 m at the river mouth (Ghionis, 1993). Nowadays, two abandoned old channels exist, on either side of the present-day active channel, with two shallow (maximum depths of <2 m) coastal lakes formed behind barrier beaches: Lake Mouria to the North and Lake Agoulinitsa, to the South of the river mouth. These lakes have been drained artificially and are used for agriculture.

In terms of the incoming wave power, the deltaic complex of the Inner Thermaikos Gulf is located within a low wave energy environment (<30 W/m/year), as compared to that of Alfios river (~25,000 W/m/year); mean annual average wave heights and periods are in the order of 0.5 m and 3.2 s, respectively, with maximum observed values in excess of 3 m and 6.5 s. The sediments of the near-mouth bottom surface are muddy (M), with some sand present (sM) very close to river mouth. Thus, the rivers Axios and Aliakmon have formed bird-foot type deltas (Galloway, 1975), whilst the delta of Alfios river is cuspate in shape. The principal morphological, climatological and hydrological characteristics of the river delta systems examined are listed in Table 1. Furthermore,

Fig. 1. Location of the deltaic coasts investigated (boxed), within Greece.