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Rapid evolution of coastal lagoons in response to human interference under rapid sea level change: A south Caspian Sea case study

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ABSTRACT

This paper examines the interdependence of different factors in the evolution of a coastal lagoon system of the Sefidrud Delta (SW Caspian Sea) based on multi-proxy sedimentary and palaeoecological analyses and remotely sensed data. According to historical aerial photographs and multiple strands of chronology, these coastal lagoons formed between 1955 and 1964, when the sea-level was relatively stable. However, formation of barrier-lagoon systems due to sea level rise is quite typical in different areas of the world, but in this case study high sediment input and longshore currents were the main driving mechanisms that permitted the establishment of a sand spit complex. After 1964, the evolution of these coastal lagoons has been mainly controlled by changing sediment input due to dam construction and rapid sea-level fluctuation. Dam flushing operations and rapid sea-level rise (~3 m between 1977 and 1995) have accelerated the infilling of the coastal lagoon system. This rapid infilling (3.1 cm y^{-1}) makes the whole system more prone to sediment encroachment in the short term. Because the lagoons are short-lived and have a dynamic evolution, rapid natural changes interact with anthropogenic modifications of the Caspian Sea environments. The short-lived nature of these lagoonal systems (total duration of 115 years for Zibakenar Lagoon) can be used as a model for lagoonal development and evolution, in other places in the world. The Caspian coast and the lagoons along it may provide a natural laboratory for what might happen in other lagoons along other coasts in the world, in response to global sea level fluctuation.

1. Introduction

The Caspian Sea (CS) with a surface area of 371,000 km^2, comparable in size with the British Isles, has experienced a ~3 m fall and rise during the 20th century (Fig. 1), while the global sea level has fluctuated approximately 2 mm/year in the same period (Kroonenberg et al., 2007). The CS offers a unique opportunity to downscale the long-term impacts of global sea level changes on coastal environments in a short time frame. Although the CS is technically a lake (Fig. 2A), its 'sea-like'—size and nature is reflected in the terminology (sea-level changes). These rapid level changes have impacted global climate (Arpe et al., 2012; Farley-Nichols and Toumi, 2014) and the lives of more than 10 million people around the CS (Dolotov and Kaplin, 2005; Kosarev, 2005; Rucevska et al., 2006; Leroy et al., 2010). Coastal geomorphology has also undergone rapid and varied changes in response to the lake level changes including passive inundation, beach-ridge formation, barrier-lagoon development and general erosion (Kaplin and Selivanov, 1995; Naderi Beni et al., 2013a). On the southern (Iranian) CS coast, major changes occurred in the Sefidrud Delta where the lagoons of Zibakenar, Ushmak and Kiashahr have developed (Fig. 2B) (Kousari, 1986; Lahijani et al., 2009; Leroy et al., 2011; Naderi Beni et al., 2013a). The lagoons are part of the Boujagh National Park, a hotspot for birds (such as cranes and pelicans) and fish (e.g. sturgeons and salmon) (Naqinezhad et al., 2006; Yousefi et al., 2012). This study focuses especially on the Zibakenar Lagoon and its infill in order to investigate the evolution of this short-lived lagoon through the lens of rapid sea-level changes. The aim of this paper is to determine when these coastal lagoons started to form, the main driving forces over time, the rate of changes and the future of this lagoonal system. The study emphasises the effects of short-term natural changes in the coastal lagoons in relation to

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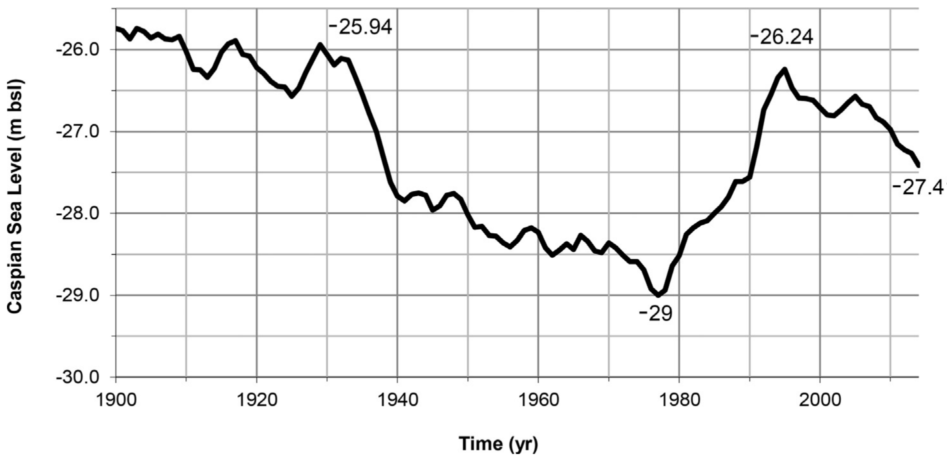

Fig. 1. Caspian Sea level (CSL) from 1900 to 1992 from Lepeshevkov et al. (1981); from 1992 to 2014 from USDA (2015).

anthropogenic effects, and demonstrates that rapid change is not only due to human action, but also due to rapid sea-level change. In this study, firstly we apply sedimentary and palaeoecological analyses to a sediment core in the Zibakenar Lagoon. Secondly, we combined multiple dating approaches including radionuclide dating, radiocarbon dating, indirect biotic dating and evidence from spheroidal carbonaceous fly-ash deposits with remote sensing techniques to understand the initiation and evolution of the Zibakenar Lagoon.

2. Study area

2.1. General geographical location

The CS is the largest closed water body in the world (Fig. 1A). Salinity in the middle and southern basins of the CS is around 13 practical salinity unit (psu), whereas it is nearly fresh in the northern basin, especially near the Volga Delta. Although most of the fresh water (~80%) is provided by the Volga River, the Sefidrud (= White River; and white has a metaphorical meaning of life-giving in Persian) supplies ~40% of the sediment entering the CS (Lahijani et al., 2008). The source of the 820 km long Sefidrud is in the Zagros Mountains in western Iran. The river passes through a narrow passage within the Alburz Mountains to reach its large delta on the southern CS shore (Lahijani et al., 2008). The Sefidrud Delta is wave-dominated during sea-level rise. During episodes of sea-level fall, the delta becomes river-dominated (Naderi Beni et al., 2013b). The Sefidrud has repeatedly changed its course through the area between the Anzali and Amirkola lagoons (Kousari, 1986) (Fig. 2B). The last major avulsion occurred around AD 1600 when the river diverted its course from the east, near Amirkola Lagoon, towards the west near Kiashahr Lagoon, shifting its outlet ~23 km westwards (Lahijani et al., 2009) (Fig. 2B). Sea level rise has been considered the main cause for river avulsion (Törnqvist, 1993; Törnqvist et al., 1996; Aslan and Autin, 1999; Jones and Schumm, 2009; Makaske, 2001; Overeem et al., 2003; Aslan et al., 2005; Hoogendoorn et al., 2005; Naderi Beni et al., 2013b). Avulsion can be caused by a decrease of river gradient as a result of several interacting processes such as subsidence, flood plain aggradation and sea level rise (Jones and Schumm, 2009; Overeem et al., 2003; Heyvaert and Baeteman, 2008). Furthermore, human activities, including channel diversion for irrigation through artificial and natural levee breaks and channel blockages, can also cause river avulsion (Heyvaert and Baeteman, 2008).

2.2. Lagoons' setting

The coastal lagoons of Zibakenar and Ushmak, located on the west side of Sefidrud, are part of a larger lagoon complex called Boujagh Lagoon (Fig. 2B). Hence, each of these lagoons is also known as the Boujagh (Boojagh, Bojagh) Lagoon. Kiashahr Lagoon (also called Farahnaz), located on the east side of Sefidrud, together with Zibakenar and Ushmak Lagoons, are part of the Boujagh National Park (BNP) (Fig. 2B) which was designated a Ramsar site in 1975. A Ramsar site is an internationally important wetland habitat designated under the Convention on Wetlands, held in 1971 in Ramsar, Iran. Most hunting activities have been banned since 1998 and the area is an important refuge for migratory birds (Naqinezhad et al., 2006). Since 2001, the area has also been designated a national park in order to decrease threats to its vegetation cover and to protect its biodiversity (Naqinezhad, 2012). The site is used for recreational and commercial fishing including aquaculture, livestock grazing, reed-cutting, limited hunting, rice farming and recreation/tourism (Annotated Ramsar List, 2011). The depth of water in these lagoons is usually less than 2 m, controlled by the level of the water table, and also by freshwater input through precipitation and irrigation.

2.3. Source of the sediments

Most of the coarse sediments in the study area are transported to the coast by the Sefidrud. Passing through a barren plateau and steep mountains, the Sefidrud, with a mean sediment discharge of ~32 million tonnes per year, provides a huge amount of eroded sediments to the CS shoreline (Lahijani et al., 2008). The south-western rivers including the Sefidrud, Kura, and Terek Rivers supply around 79% of sediment to the CS (42, 22, and 15%, respectively) (Lahijani et al., 2008). These sediments are redistributed mainly by waves and wave-induced longshore currents. The prevailing currents are southward in Azerbaijan and along the west Iranian coast (Lahijani et al., 2009). With the latter currents, sediments originating from the western rivers (e.g. Kura River) also contribute to the sediment supply in the area (Doriniana and Myakokin, 1972). These longshore currents supply sediment for the development of spit-barrier systems and associated lagoons (Kaplin and Selivanov, 1995; Kroonenberg et al., 2000; Lahijani et al., 2009) such as the Anzali, Zibakenar, Kiashahr and Amirkola lagoons (Kousari, 1986; Lahijani et al., 2009; Naderi Beni et al., 2013b). Furthermore, the prevalent winds, combined with proximal availability of barren

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