Journal of African Earth Sciences 121 (2016) 168–179

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Surface sediment dynamics along the shore of Hammamet Gulf (Tunisia, southern Mediterranean)

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ARTICLE INFO

Article history:
Received 31 March 2016
Received in revised form
31 May 2016
Accepted 1 June 2016
Available online 3 June 2016

Keywords:
Hammamet Gulf
Particle size
Minerals
Currents
Sediment dynamics

ABSTRACT

In the summer of 2015 the authors analysed grain size and surface sediment composition through high spatial resolution from samples taken at 53 stations along the Hammamet coast (southern Mediterranean Sea). The Acoustic Doppler Current Profiler deployed in this study showed that the surface current flows toward the north-east, parallel to the coast at a maximum speed along the main axis of about 5.9 cm s^{-1}. Near the bottom the current flows toward the north-west at a maximum speed of 2.2 cm s^{-1}. The tide plays a relatively small role in water circulation in Hammamet Gulf. Spatial distribution of particle size, along with speed and current direction analysis, furnish an overview of the gulf's sediment dynamics and transport. The sands are categorised as moderately sorted, well sorted or very well sorted. Particle size distribution of surface sediments from the coast to a depth of 25 m offshore shows a decreasing trend in the offshore direction. Mineralogical analysis shows that Hammamet's coastal sands are composed of two main minerals: quartz and calcite. Magnesium calcite and aragonite are present in small amounts.

Sediment dynamics along the Hammamet Gulf shores are complex, being subject to the effect of swells and secondarily of tides. We encourage the implementation of responsible environmental management procedures in order to help preserve the site.

1. Introduction

Along its 1300 km coastline, eastern Tunisia is endowed with a wide variety of environments and natural landscapes, along with an archaeological heritage of great value (Hannachi et al., 2011; Anane et al., 2014; Khiari et al., 2016). This stretch of coastline, known as the coast of Ennefidha, concentrates more than 60% of the country's population and nearly all of its touristic and industrial activities (Afli et al., 2008). This affects the coastal environment, the landscape and land cover patterns, and intensifies erosion (Ben Romdhane et al., 2002; Trabelsi et al., 2013), yet no information on spatial distribution, composition or size of mineral particles is available, nor have any investigations been undertaken of the influence of the area's currents, winds and waves on particle erosion, transport or deposition. This is unfortunate since it is recognised that, for example, 1) the Ennefidha coastline's sediment balance is highly sensitive to any changes occurring in the environment due to human or natural interference, and 2) trace elements causing harm to marine biotas and flora (Galgani et al., 2009; Zaaboub et al., 2015; Martins et al., 2016; Helali et al., 2016) are usually associated with fine-grained sediments due to their high surface-to-volume ratios and adsorption capability (Belabed et al., 2013; Helali et al., 2016).

Located within this eastern coastal zone, the shore of Hammamet Gulf, which harbours the marina of Yasmine Hammamet and the Sahel domain (Fig. 1), concentrates nearly half of the country's tourist potential. The area is currently undergoing a growth in industrial activity which is endangering the environment (Elgharsalli et al., 2015), and shows signs of a precarious balance along the coastline (beach erosion processes and shoreline retreat). In particular, there is a worrying process of erosion on the coastline as 40 of the 500 km of sandy coast are seriously affected. Indeed, between Bouficha and Hergla, the hydrographic network is dense but no streams flow directly into the sea; their waters accumulate in sabkhas—an Arabic word designating a coastal and inland saline mud flat built up by the deposition of silt, clay and sand in shallow depressions—along the coast (Brahim et al., 2015a,b). During floods, the sabkhas overflow and sediment particles transported along the watershed become a valuable source of sediments to the beach. Two dams have been built on Lebna and Chiba Streams. The

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http://dx.doi.org/10.1016/j.jafrearsci.2016.06.001
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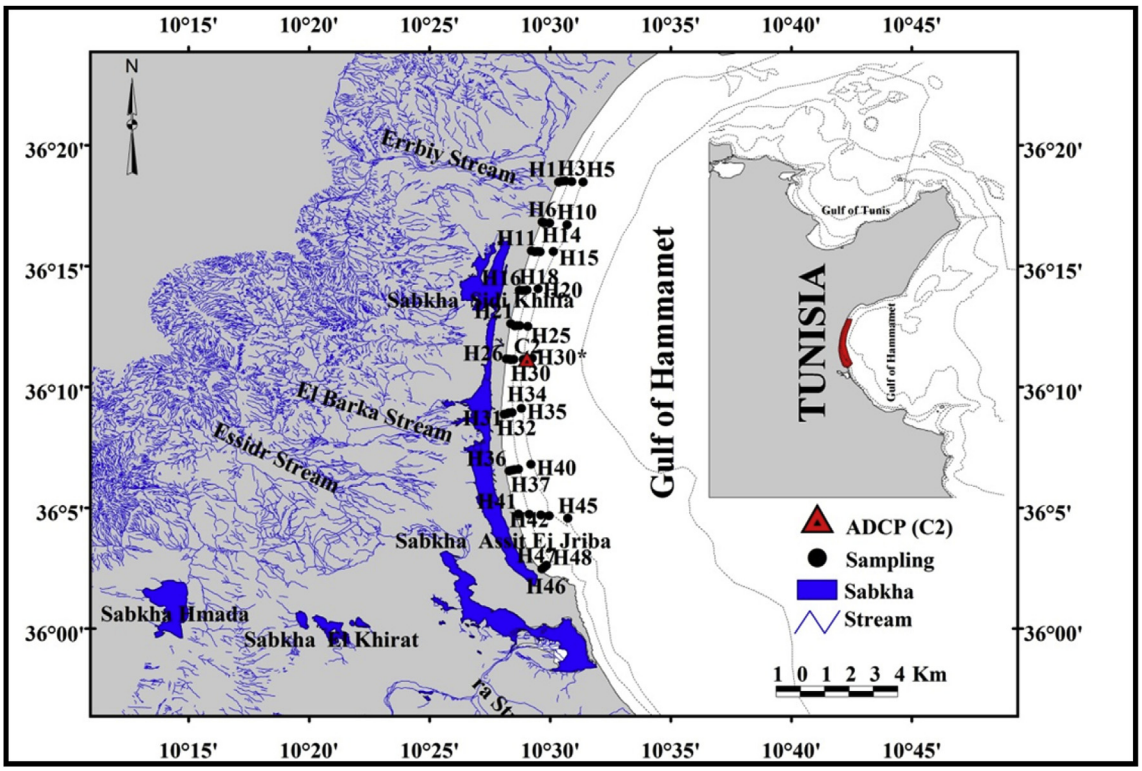

Fig. 1. Sediment sampling station locations and position of the current meter.

sediment contributions carried by the Lebna in the years 1972–73 were estimated at 10.6×10^6 m^3. The volume of sediment retained by the Chiba Stream Dam between 1973 and 1975 attained 7.86×10^6 m^3 (DGRE, 2008). These quantities of sand carried down by rivers and collected by the two dams no longer reach the sea. Consequently, the sedimentary stock available at the mouths of these streams has been substantially reduced since dam construction, resulting in additional shoreline retreat.

Furthermore, the seagrass beds of *Posidonia* of Hammamet and of North Hergla, which respectively occupy surfaces of 10.5 and 8.5 km^2, are declining, though they play an important role in sediment dynamics (Ben Brahim et al., 2010, 2014). For instance, seagrass beds play pivotal role in the structure and dynamics of many coastal and estuarine benthic systems (Infantes et al., 2011, 2012; Ben Brahim et al., 2014) protecting for example sediments from resuspension through dissipating water energy (Gacia and Duarte, 2001; Ben Brahim et al., 2015). The total area of seagrass beds is estimated at about 167 km^2 in Hammamet Gulf (Ben Mustapha and Hatour, 1992). The *Cemodocea* beds in the gulf are present at depths of 6–40 m (Amari, 1984), sometimes alternating with barren sandbars, and are influenced by important sedimentary dynamics.

It has therefore become urgent to address this important question: what are the principal mechanisms driving sediment dynamics along the coast of Ennefidha? To answer this question, we have used high spatial resolution to analyse the hydrodynamics, grain size and mineral composition of surface sediments along this coast.

2. Materials and methods

2.1. Study area

Hammamet Gulf is located in north-eastern Tunisia. It is surrounded by Cap Bon to the north, the plain of Ennefidha to the west, the plains of the Sahel to the south and the Mediterranean Sea to the east. The shoreline is characterised by wide sandy beaches and the presence of salt pans (Oueslati, 2004).

The area's border zones are of the Quaternary age and their geological formations show lithological sandy clay facies. Between southern Hammamet and Hergla, the entire coastline is in balance, particularly the long deserted beach stretching from Selloum Hergla to Madfoun where the beach is bordered by a remarkable shorefront dune (Colleuil, 1976; El Batti, 1974).

Between Bouficha and Hergla, the hydrographic network is dense but no streams flow directly into the sea; their waters accumulate in sabkhas—an Arabic word designating a coastal and inland saline mud flat built up by the deposition of silt, clay and sand in shallow depressions—along the coast (Brahim et al., 2015a,b). During floods, the sabkhas overflow and sediment particles transported along the watershed become a valuable source of sediments to the beach.

Two dams have been built on Lebna and Chiba Streams. The sediment contributions carried by the Lebna in the years 1972–73 were estimated at 10.6×10^6 m^3. The volume of sediment retained by the Chiba Stream Dam between 1973 and 1975 attained 7.86×10^6 m^3 (DGRE, 2008). These quantities of sand carried down by rivers and collected by the two dams no longer reach the sea. Consequently, the sedimentary stock available at the mouths of these streams has been substantially reduced since dam construction, resulting in additional shoreline retreat.

The western Mediterranean's Atlantic Water (AT) current enters the Straits of Sicily to split into two branches: one flowing to the south-eastern Mediterranean and the second, called the Atlantic Tunisian Current (ATC), flowing southwards along the Tunisian coast and directly affecting circulation at the mouth of the gulf (Ben Ismail et al., 2012, 2014). According to nautical instructions a north-south current flows along the eastern coast of Tunisia, accompanied