Marine Pollution Bulletin 110 (2016) 65–74

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Environmental quality in sediments of Cadiz and Algeciras Bays based on a weight of evidence approach (southern Spanish coast)

José Antonio Usero [a], Daniel Rosado [b,c,*], José Usero [b], José Morillo [b]

[a] INERCO S.A., Parque Tecnológico y Científico Isla de la Cartuja, Calle Tomás Alba Edison, 2, 41092 Sevilla, Spain
[b] Department of Chemical and Environmental Engineering, Universidad de Sevilla, 41092 Sevilla, Spain
[c] Department of Chemistry, Universidad Técnica Particular de Loja, 11 01 608 Loja, Ecuador

ARTICLE INFO

Article history:
Received 15 May 2016
Received in revised form 16 June 2016
Accepted 22 June 2016
Available online 30 June 2016

Keywords:
Sediment quality
Ecological risk assessment
Trace metals
Sediment toxicity
Benthic macroinvertebrates
Cadiz Algeciras Bays

ABSTRACT

This research applies an integrated sediment quality assessment method using a weight of evidence approach to Cadiz and Algeciras Bays (southern Spain). The method is composed of several analyses (particle size profile, aqua regia extractable metals, acid labile metals, total organic carbon, toxicity bioassay with *Photobacterium phosphoreum* and macrobenthic community alteration).
The proposed method provides a single result, the environmental degradation index (EDI). EDI defined samples as low degraded (outer areas of both bays) and moderately degraded (Inner Bay of Cadiz Bay, the surroundings of Algeciras port and the northern part of Algeciras Bay). These samples showed the highest concentration of aqua regia extractable metals, which exceeded effects range-low (ERL) for Zn (51–176 mg/l), Cu (11–54 mg/l), As (4.3–9.5 mg/l), Hg (0.17–0.28 mg/l), Ni (23–82 mg/l), and. Cr (37–134 mg/l). They also exceeded some quality criteria for total organic carbon (4.0–6.5%) and toxicity (120–240 TU/g) and showed poor results for macrobenthic community.

1. Introduction

Waste has been dumped into the aquatic ecosystems for decades (Ahuja, 2013; Earnhart, 2013), and pollution is reaching worrying levels in some areas (Baldassin et al., 2016; Vandermeersch et al., 2015; Zhou et al., 2016). In the aquatic environment, many pollutants bind onto sediments and can reach concentrations higher than those in the water column. Changes in environmental conditions, such as pH or redox potential, can release a fraction of the contaminants retained in the sediments and re-solubilize them in water (Wang et al., 2015) . Thus, sediments may act as a sink or a source of contamination and, in the latter case, may affect aquatic life, or even humans, through the food chain (Mackay et al., 2016). This was the case of Minamata Bay and the Jinzu River basin (Horiguchi, 2014; Mason et al., 2006; Tomiyasu et al., 2006). The population of Minamata Bay was exposed to methylmercury through the consumption of seafood during the 50s and 60s of the last century. Methylmercury was discharged into the sea by a nearby factory and caused mental disorders to between 700 and 4000 people and death to a percentage of them (Harrison, 2001). Regarding the Jinzu River, mining companies released cadmium into the river during the last century. The river was used mainly for irrigation of rice fields. This led to high cadmium levels in the people fed with this rice and itai itai disease (Horiguchi, 2014). As of July 2009, 195 persons were officially designated as Itai-Itai disease patients in the region (Nogawa and Suwazono, 2011).

Because of this, contaminants in the sediments of aquatic ecosystems have become one of the most important environmental problem at present (Chapman and Wang, 2001; Ruiz et al., 2008; Sainz and Ruiz, 2006) and many researches are carried out in this topic (Chapman and Smith, 2012; Chapman et al., 2013; Foster et al., 2015; Nowell et al., 2016; Rosado et al., 2016, 2015a; Testa et al., 2013; Yunker et al., 2015).

Trace elements are bioavailable and persistent in the environment causing bioaccumulation and toxicity effects in the biota. Typically, benthic invertebrates start bioaccumulation by both the absorption from interstitial water and ingested sediment and transfer them to higher trophic levels, extending the hazard (Conti et al., 2016). The uptake of trace metals by benthic organisms depends largely on their chemical forms (Morillo et al., 2008).

Integrated sediment quality assessment methods using a weight of evidence (WOE) approach measure and integrate metrics from different lines of evidence, e.g., chemical characterization, toxicity testing, and biological surveys (Anderson et al., 2003; Chapman, 2002, 1992, 1990; Chapman et al., 1997; Cherry, 2001; Crane, 2003; Ghirardini et al., 1999; Khosrovyan et al., 2015; Long and Chapman, 1985; Qi et al., 2015). This allows to conduct a comprehensive assessment of the quality of sediment, as they provide more reliable information than the use of single techniques (Buruaem et al., 2013; Chapman and Hollert, 2006; Chapman, 2007; Riba et al., 2004).

* Corresponding author at: Department of Chemical and Environmental Engineering, Universidad de Sevilla, Camino de los Descubrimientos, s/n, 41092 Sevilla, Spain.
E-mail addresses: danrosalc@alum.us.es, djrosado@utpl.edu.ec (D. Rosado).

http://dx.doi.org/10.1016/j.marpolbul.2016.06.078
0025-326X/

This research has two main objectives. First, to test a modified version of an integrated sediment quality assessment method previously proposed by Rosado et al. (2015b) using a WOE approach which is simple, low-cost and provides an easily understandable and comparable result. Second, to implement the modified version of the integrated sediment quality assessment method in the Algeciras and Cadiz Bays, where anthropogenic sources of pollutants and areas of high ecological and economic value coexist in a relatively small zone.

2. Study area

The areas studied are the bays of Cadiz and Algeciras, located in southern Spain (Fig. 1), whose sediments are affected by discharges from major urban centers, large and small industries, intense port activity and, to a lesser extent, farming.

2.1. Cadiz Bay

Cadiz Bay is located in the southwest of the Spanish Atlantic coast, between the town of Rota and the city of Cadiz, and covers an area of 110 km^2. It can be divided into two main maritime regions. The Inner Bay, located south of the bridge José Leon de Carranza, is characterized by a maximum depth of five meters and a low rate of water renewal, which favors accumulation of pollutants discharged. The Outer Bay, that is extended northward from the bridge up to Rota, is deeper, open to the Atlantic Ocean and thus, the renewal of its waters is faster (Araújo et al., 2009; Ligero et al., 2002, 2004).

The prevailing currents in the coasts of the Gulf of Cadiz come from west-northwest generating an anticlockwise circular current in the Outer Bay. The Inner Bay is protected from the surge and, partially, the wind, so water dynamics are tidally controlled causing a less defined current with several gyres (Ligero et al., 2002; Periáñez, 2009; Periáñez et al., 2013). In the Outer Bay empties the Guadalete River, the main river in the area.

Cadiz Bay hosts several towns (Rota, El Puerto de Santa María, Puerto Real, San Fernando, Chiclana de la Frontera and Cadiz) whose population exceeds 400,000 inhabitants (Carrasco et al., 2003). In this bay also takes place a remarkable industrial activity, including shipyards and car and aircraft components manufacturers. Furthermore, there is a high maritime traffic due to merchant ships and, increasingly, to cruises and ferries between the Iberian Peninsula and the north of Africa and the Canary Islands.

Cadiz Bay includes some areas cataloged as Special Protection Area under European Union's Birds Directive: the Cadiz Bay Natural Park and the Trocadero Island and Sancti Petri Marshes nature reserves.

2.2. Algeciras Bay

Algeciras Bay is located on the southern end of the Iberian Peninsula, next to the Strait of Gibraltar, between two important water bodies, the Atlantic Ocean and the Mediterranean Sea, and two continents, Europe and Africa. This bay is a semi-enclosed water body in a horseshoe shape, with a maximum width of 9 km and a north-south length of about 10 km. The endpoints that define the mouth of the bay are Punta Carnero in the west and Punta Europa in the east, defining a water surface of about 75 km^2 with a depth of up to 400 m (Sammartino et al., 2014). The main rivers which drain into the bay are the Guadarranque and Palmones rivers.

Westerly winds are predominant in the area and they lead to a clockwise water circulation, i.e., runs along the coast starting at the west end (Punta Carnero) to the east end (Punta Europa). This current can be switched to anticlockwise in the case of easterly winds (Periáñez, 2012; Sánchez-Garrido et al., 2014). The maximum tidal stands at 0.8 m along the entire shore (Periáñez, 2012).

Five important cities located around the bay (Algeciras, Los Barrios, San Roque, La Línea de la Concepción and Gibraltar) are home to more than 250,000 inhabitants (Kosore et al., 2015). The major industries in the area are mainly located in the northern part of the bay and include petrochemical and petroleum refineries, a stainless steel manufacturing

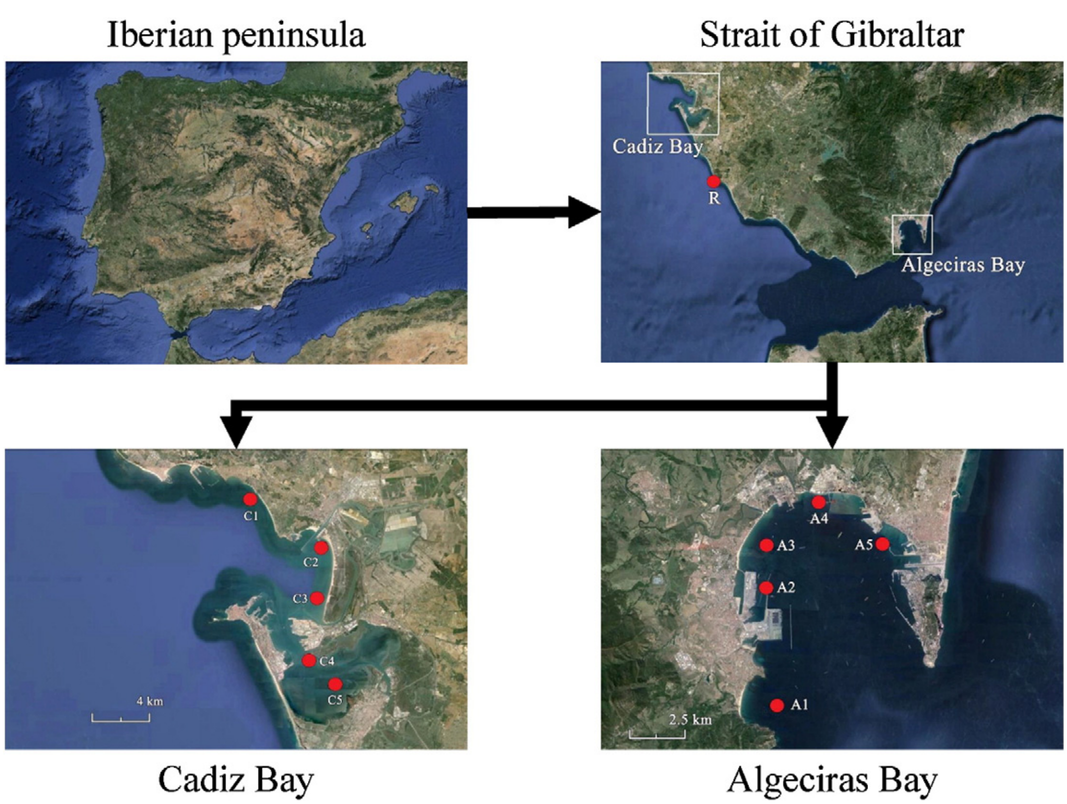

Fig. 1. Location of the sampling points in Cadiz and Algeciras Bays.