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Assessment of susceptibility to pollution in littoral waters using the concept of recovery time

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ABSTRACT

Susceptibility to pollution can be related to the flushing capacity of aquatic systems. Transport time scales constitute a useful tool for representing the water exchange and transport processes. A new transport time scale, recovery time, and a methodology to estimate it by means of numerical models is hereby developed. Recovery time, calculated in Gijon, Santander and Tarragona harbours, is significantly related to physical, chemical and biological water quality indicators. Susceptibility, assessed through recovery time values, provides spatial patterns of expected flushing capacity, being sensitive to physical and hydrodynamic characteristics. The developed method is appropriate to estimate recovery time and assess susceptibility against pollution in littoral waters having great potential to be applied to different disciplines. Recovery time could be used in littoral waters as a surrogate of water quality indicators, to establish efficient monitoring programs, to define and characterize modified water bodies or to improve the design of marine infrastructures.

1. Introduction

The environmental response of an aquatic system to an input of pollutants greatly depends on its inherent susceptibility, i.e., natural capacity to absorb environmental stress and still easily recover stability (Kvaerner et al., 2006). A high susceptibility implies that the aquatic system is so intensively and extensively altered that it is difficult for it to return to its initial state. Thus, highly susceptible locations have low ability to recover and return to their original state, i.e. low resilience (Nilsson and Grelsson, 1995).

In littoral waters, susceptibility to anthropogenic factors is related to the time required for the coastal feature to recover its initial conditions (Pethick and Crooks, 2000). Therefore, susceptibility to pollution can be related to the cleaning capacity of aquatic systems, or to the time a contaminant persists in it (Nilsson and Grelsson, 1995; Orfila et al., 2005; Shen and Haas, 2004), meaning that areas with a shorter retention of contaminants (quicker flushing) will be less susceptible to contaminant discharges than those with longer retentions (Abdelrhman, 2005; DiLorenzo et al., 1994).

The intrinsic cleaning capacity of an aquatic environment can be represented by two different types of processes: physical and biogeochemical. Physical transport and mixing processes seem to dictate the environmental conditions that control the occurrence of biogeochemical processes (Cucco and Umgiesser, 2006; Cucco et al., 2009). The description of the transport process, through advection and diffusion, can be expressed by the definition of transport time scales (henceforth TTS) (Cucco et al., 2009). TTS are considered the main factor for water quality through the control of concentrations and the accumulative capacity of all the substances (Orfila et al., 2005; Shen and Haas, 2004; Yuan et al., 2006). TTS are important physical parameters in aquatic systems and constitute a useful tool for representing the water exchange or transport processes (Takeoka, 1984). For this reason, TTS can be used as an indicator of susceptibility of a water system to a pollutant input. A TTS which is able to assess the susceptibility against pollution should (a) estimate the time taken to recover its initial condition, (b) provide a spatial distribution and (c) be correlated with environmental quality variables.

Multiple concepts for TTS are referenced in the scientific literature, with flushing and residence time being the most commonly used (Abdelrhman, 2005; Monsen et al., 2002; Wang et al., 2004). Both TTS have been widely studied by analyzing the transport of a hypothetical tracer in a numerically modelled experiment. Flushing time is considered to be the average time required

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to change the entire water volume in a particular domain (Monsen et al., 2002). It describes the general exchange characteristics of a domain generally conceived as a water body (discrete, significant, and delimited area), so it does not provide a spatial distribution. Residence time is defined as the time it takes for any water parcel to leave the domain through its boundaries (Hilton et al., 1998). Residence time has been mainly used in enclosed aquatic systems (lakes, reservoirs or estuaries). For littoral waters however, which do not have physical domain boundaries, residence time values would represent the time required per each water parcel to exit the domain, instead of representing the time required to recover its initial conditions.

In this paper, a new TTS was defined to assess susceptibility to the retention of contaminants in aquatic systems: recovery time (henceforth RT). The numerically modelled hypothetical tracer experiment conducted for this study shows a possible contaminant which has been introduced into a water parcel, and how the water parcel is unable to recover until the contaminant has exited the water parcel. RT is achieved when tracer concentration in the water parcel reaches 0.1% of its initial value. Therefore, a water parcel with high RT will be more susceptible to a pollution impact than one which is well flushed.

The goal of this paper is to study the relation between RT values and environmental data in coastal areas and estuaries with different physical and hydrodynamic characteristics (i.e. Spanish harbours). To reach this objective, a methodological procedure to calculate RT was developed and an evaluation criterion to assess susceptibility from RT values was defined.

2. Site descriptions

The study was carried out on three coastal sites located along the Iberian Peninsula: Gijon, Santander and Tarragona (Fig. 1), with a diverse hydrodynamic conditions and flushing capacities for each site due to the presence of port infrastructures.

The coastal zone of Gijon, located on the Northern coast of Spain, in the Cantabrian Sea, exhibits a semidiurnal tide with a medium tidal range of 2.8 m. The most frequent wind events in this area come from the west (17.8%) and northwest (14.5%) directions (Table 1). Piles River, with a basin drainage area of about 85 km^2, has an average annual flow of 1.1 m^3/s (García et al., 2010). The Port of Gijon has become a link between the Iberian Peninsula and the Northern and Southern Europe (González-Marco et al., 2008). Nowadays, the Port of Gijon is more than a basic node of transport system; it is focal point for activities ranging from the transport of dangerous cargo to recreational use in bathing waters. The domain under study, with 48.2 km^2, is the harbour area limited between the meridians 5°38′W and 5°42.52′W and parallel 43°37′N (Ministerial Order FOM/297/2008). Gijon port infrastructures allow obtaining areas with different flushing capacity.

The Bay of Santander is one of the most important estuaries of the North of Spain, with a total extension of 22.5 km^2, housing a Special Protection Area (SPA). The aquatic environment in the Bay of Santander is characterized by hydrodynamic conditions controlled by a semidiurnal tidal regime, with a medium tidal range of 2.9 m, interacting with freshwater discharges and prevailing West winds (Puente et al., 2002). Cubas River is the main freshwater discharge, with an average annual flow of 8.0 m^3/s (Table 1). Although hydromorphological alterations are less important than in Gijon or Tarragona, these provide a variability regarding the flushing capacity of the environment. The domain under study is the harbour area (37.4 km^2), limited by the alignment between Cabo Mayor and Cabo Ajo lighthouses up to the intersection with the meridian 3°43′44″W (Ministerial Order FOM/709/2012). Santander's port is a natural harbour with four docks for general cargo located on the left bank of the bay.

Tarragona is located in the Mediterranean Sea. It's hydrodynamic are governed by a mixed and microtidal regime, with a mean tidal range of 0.2 m, Northwest winds and the Francolí River. The Francolí River, located inside the port, presents an average annual flow of 1.4 m^3/s (Table 1). The port of Tarragona is one of the most important in Spain in terms of freight traffic (Artiñano et al., 2007). The domain is limited by the intersection of two points (1°20.21′, 41°1′) and (1°19.22′, 41°5′) and their projection by perpendicular lines to the coastline, with a surface area of 31.6 km^2. It is expected that hydromorphological elements strongly influence the water flushing capacity in Tarragona.

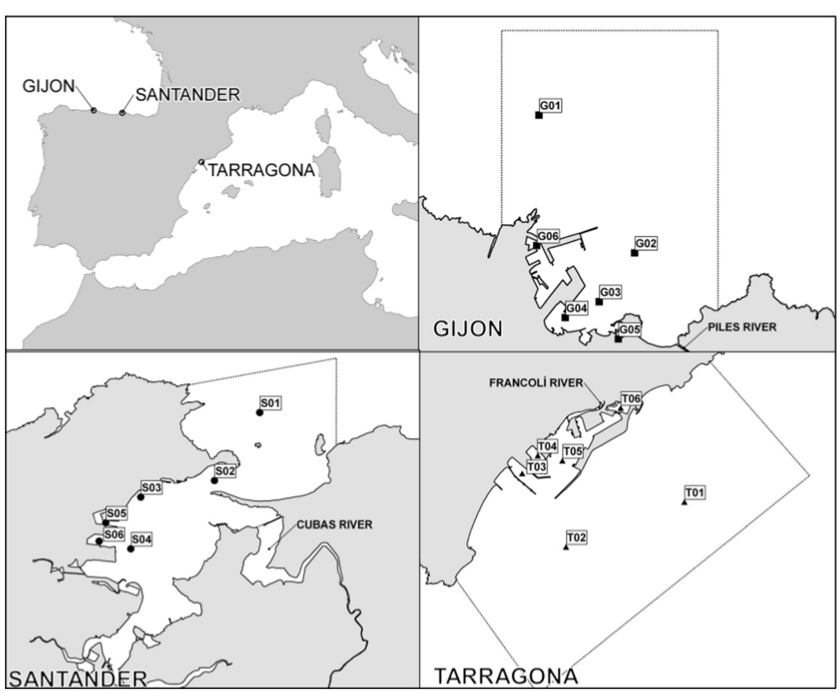

Fig. 1. Location of sites and sampling stations.