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Variation of sedimentation rate in the semi-enclosed bay determined by ^{137}Cs distribution in sediment (Kaštela Bay, Croatia)

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ABSTRACT

Purpose of this research was to study the rate at which the semi-enclosed bay such as the Kaštela Bay reacts to the coastal processes of industrialization and urbanization, the extent of the influence of human activities on the bay, and the sediment distribution affected by anthropogenic influence. Temporal and spatial sedimentation rate variations were observed between three studied periods: 1954–2005, 1963–2005/2006, and 1986–2005/2006. Sedimentation rates were in the following ranges: 0.29–0.49 cm/yr for the 1954–2005 period, 0.58–0.95 cm/yr for the 1963–2005/2006 period, and 0.50–1.32 cm/yr for the 1986–2005/2006 period. The average total sedimentation rates for three periods were 0.41 cm/yr, 0.81 cm/yr, and 0.61 cm/yr, respectively. Sedimentation rate for the individual 1963–1986 period marked with two ^{137}Cs marker peaks was in the 0.65–1.30 cm/yr range, while the mean value was 1.06 cm/yr. Long-term sedimentation rate increase in the whole Kaštela Bay was observed and clearly connected to the industrialization and urbanization processes in the coastal area. These processes reflect very quickly, in terms of years, in the sedimentation rates. Intensive anthropogenic activities in the coastal area are reflected in the whole bay depending on the amount of the discharged sediment material, topography of the sea bottom, and water currents. Some localized areas of sediment accumulation may form.

1. Introduction

Coastal areas are particularly important for human activities which makes the marine environment receiving discharges from these areas very sensitive to anthropogenic influence. It has been established that urbanization and industrialization are among the processes with the largest direct influence on the sedimentation rate changes in the coastal areas (Lu and Matsumoto, 2005).

^{137}Cs is probably the most frequently used anthropogenic radionuclide for monitoring of the environmental processes (Ayçık et al., 2004; Saxena et al., 2002). It is also one of the most frequently applied tracers for determination of recent sedimentation rates in aquatic environments (Ahn et al., 2006; Kumar et al., 2007; Laissaoui et al., 2008; Lu, 2004; San Miguel et al., 2004; Yao et al., 2008). Determination of the sedimentation rates with the ^{137}Cs method is suitable for sediments of up to 100 years old (Ahn et al., 2006; Mizugaki et al., 2006; Saxena et al., 2002; Schell and Barnes, 1986). ^{137}Cs distribution in undisturbed sediment depth profiles reflects the global deposition pattern of ^{137}Cs due to the atmospheric fallout. It is, therefore, possible to determine the maximum ^{137}Cs activities in sediment columns corresponding to the times of maximum ^{137}Cs input into the environment. This enables its use as a global geochronological marker.

Kaštela Bay coastal area is one of the most industrialized, most urbanized and most densely populated areas in Croatia. It comprises the city of Split, Kaštela, Solin, and Trogir towns, representing the largest urban agglomeration on the east Adriatic coast. Since the 1950s this area was intensively industrialized and urbanized resulting in a sudden and multiple increase of population. The Split urban region had the most dynamic growth in the second half of the 20th century. Population of the city itself increased 3.5 times in app. 50 years (Kranjčević et al., 2014). The past and present industrial activities include chemical factory “Adriavinil”, cementworks, ironwork and galvanization facility, shipyard, all located in the east part of the area. Agricultural activities are more significant in the west part of the area. However, intensive industrialization and urbanization were not followed by the intensive infrastructure development and various contaminants were discharged into the

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Bay. Large amounts of untreated sewage waste waters, runoff, and industrial waters were discharged into the Bay for decades and TENORM was also deposited in the Bay (Margeta, 2002; Ujević et al., 2000) influencing sediment quality in the Bay (Orescanin et al., 2005). These discharges represented a significant anthropogenic source of particulate matter for deposition in the Bay.

The aim of this study was to determine influence of the anthropogenic activities on the sedimentation rates in the Bay considering a significant anthropogenic source of sediment material and spatially concentrated industrial activity and population density. The purpose was to study the rate at which the semi-enclosed bay reacts to the more or less intensive coastal processes of industrialization and urbanization, the extent of the influence of the human activities on the bay, and the sediment distribution affected by anthropogenic influence.

2. Material and methods

2.1. Study area

Kaštela Bay is a semi-enclosed bay with a low-energy environment and one of the largest bays on the east Adriatic coast (Marasović et al., 2005; Margeta, 2002). It is located in the central Adriatic Sea close to the City of Split (Fig. 1). In its western part it is connected with the Trogir Bay through the narrow Trogir Channel and in the south-east it is connected with the Split and Brač Channels by wide "gates" between the Split peninsula and the Čiovo Island. Despite their connection, Kaštela Bay and Split and Brač Channels represent separated marine basins due to different ecological characteristics and terrestrial influences. The Bay is 14.8 km long and 6.6 km wide (Tudor, 1993). Its total area is app. 60 km^2, average depth 23 m, and maximum depth 45–50 m at the entrance of the Bay (Kljaković-Gašpić et al., 2006; Marasović et al., 2005).

According to bathymetric and morphological characteristics two distinctive parts of the Kaštela Bay are differentiated: deeper central and east part and shallower west part of the Bay (Fig. 2). Surface sediments of the Kaštela Bay bottom are presented in Fig. 3. The largest part of the Bay is covered with muddy sediments while coarse grained sediments are mostly distributed in the shallow west part and along the north coast of the Bay.

Based on changes in oxygen concentrations in surface and bottom water, primary production, water transparency, phytoplankton composition, and other physical, chemical, and biological parameters it was concluded that the eutrophication in the Kaštela Bay has started at the beginning of the 1970s pointing to the contamination with high concentrations of nutrients of anthropogenic origin (Barić et al., 1992). The Bay was characterized as a eutrophic to highly eutrophic area, especially its east part. The main sources of contamination, including excess organic matter, in the Bay were considered to be untreated industrial and municipal waste waters and urban area runoff (Bogner et al., 1998; Milun et al., 2004, 2006; Ujević et al., 1998a) containing high concentrations of organic matter. These effluents were discharged mostly into the east part of the Bay.

Vertical stratification of the water column occurs in the warm period of the year (from April to October), with the thermocline present at 10–25 m depth, while during the winter (from November to March) the water column is well mixed (Kljaković-Gašpić et al., 2006; Margeta, 2002). Circulation in the surface water layer of the Bay is predominantly of the cyclonic direction (Kljaković-Gašpić et al., 2006; Zore-Armanda, 1980). This type of circulation is established under the influence of the bora (NE wind) and mistral (NW wind) winds. Anticyclonic circulation is established under the influence of the scirocco wind (SE wind) (Zore-Armanda, 1980). A combination of these two circulation types is also possible. Although the Kaštela Bay is a separate water body separated from the Brač and Split Channels, the exchange of water between the Kaštela Bay and the Brač Channel exists as a consequence of the wind influence mostly (Marasović et al., 2005). The average water replacement time in the whole Bay is app. one month and in the east part of the Bay app. 15 days which can be reduced to five days in cases of strong winds (Marasović et al., 2005; Margeta, 2002). Wind influence is relatively weak and the fresh water inflow is low during the warmest part of the year (from July to September) causing long water replacement time in the Bay. Closed circular current is formed in the east part of the Bay during the summer months. Hence, almost no water exchange occurs between the east part of the Bay and its other parts (Barić, 1995).

The coastal area around the Bay and its hinterland are generally built of two types of rocks (Fig. 2). The predominant rocks on the north coast of the Bay and the Split peninsula are flysch and flysch-like rocks while the Čiovo Island and the hinterland are mostly built of different varieties of limestones with some dolomites (Marinčić et al., 1971). The carbonate rocks are intensively karstified and fractured which has a significant influence on the hydrographic net around the Bay. The only permanent surface stream is the Jadro River in the easternmost part of the Bay (Fig. 1) representing the

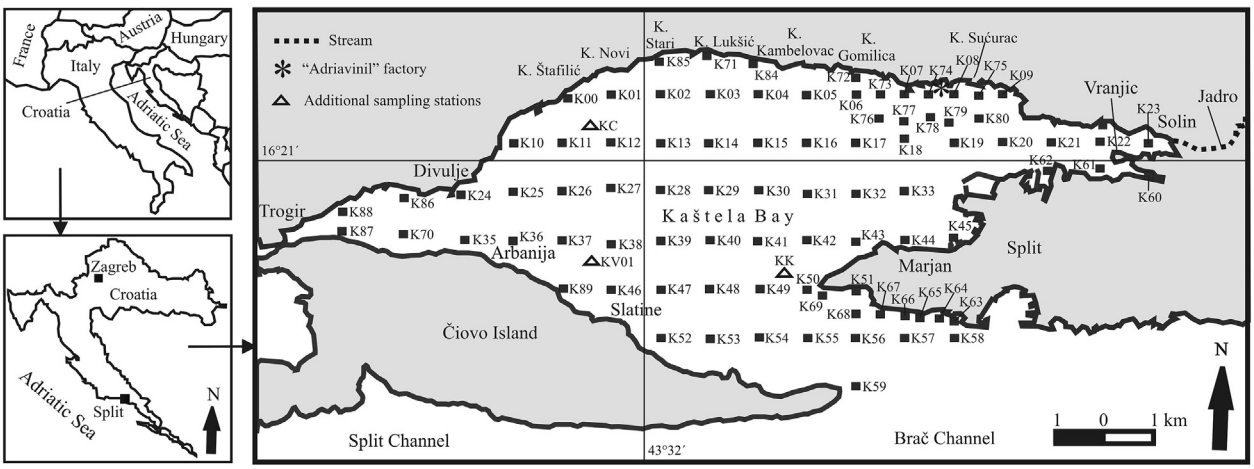

Fig. 1. Location of the Kaštela Bay and the sampling stations.

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