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Baseline

Seasonal distribution of metals in vertical and horizontal profiles of sheltered and exposed beaches on Polish coast

Katarzyna Bigus [a], Aleksander Astel [a,*], Przemysław Niedzielski [b]

[a] Pomeranian University in Słupsk, Institute of Biology and Environmental Protection, Department of Environmental Chemistry, Arciszewskiego 22B, 76-200 Słupsk, Poland
[b] Department of Analytical Chemistry, Faculty of Chemistry, Adam Mickiewicz University, Umultowska 89, 61-614 Poznań, Poland

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ABSTRACT

The distribution of alkali and heavy metals in coastal sediments of three Polish beaches was assessed. In all locations there are sandy beaches of different characteristics according to the anthropogenic impact and degree of sheltering. Core sediments collected in Czołpino and Ustka were characterized by the highest concentration of Cd, Ag, Ba, and Al, Cu, Cr, Bi, Na, respectively. Among the alkaline metals core sediments were the most abundant with Ca, Bi, Mg and Na, presenting almost stable decreasing order in all beaches. The majority of dredge material collected can be classified as light or trace contaminated by Cr, Cu, Zn, Cd and Hg. An abundance of mineralogical components in core sediments in Ustka increases in Summer and Autumn, while in Puck is stable throughout the year. The content of studied metals in core sediments collected in three Polish beaches changes both in the vertical and horizontal profiles of the beach.

Sea coasts are contact zones between the land and the sea or ocean. One of the few possible types of coasts is beaches, which are the most common form of littoral accumulation. Sandy beaches being a considerable part of marine coastal ecosystems are an extremely dynamic environmental compartment whose structure is determined by the wind, sand and water in the state of constant motion (Brown and McLachlan, 1990). Beach sand filters large quantities of sea waters as well as ground waters. Therefore, the beach makes up a specific purgative filter, protecting land ecosystems from penetration of pollution coming from sea (Trojanowski et al., 2014). Consecutively, the filtration leads to excessive accumulation of organic matter, pollutants and toxic substances in the beach sediments (Bigus and Trojanowski, 2011).

Marine beaches are often subjected to considerable anthropogenic pressure resulting from their recreational and economic functions (Węsławski et al., 2000) since more than half of the world's human population lives within 60 km from the coastline, and the number is constantly increasing. Therefore, the human impact on the coastal environment is enormous. It is estimated that more than 90% of contaminants getting into the marine ecosystem comes from the land, and is a direct result of human activity. Particularly troublesome contaminants include heavy metals, petroleum substances, biogenic substances and microbial contamination. Heavy metals are among the most common environmental pollutants, and their occurrence in water and sediments indicates the presence of natural or anthropogenic sources.

The main natural sources of metals in waters are chemical weathering of minerals in rocks and soil leaching. The anthropogenic sources are associated mainly with industrial and domestic effluents, urbanism, water runoff and landfill sources (Andrulewicz, 1994 and Gheskiere et al., 2005). Heavy metals are introduced into the environment by all human activities associated with obtaining energy. Generally, 3 to 10 times more of heavy metals is introduced into the environment from anthropogenic sources in comparison to natural ones (Korzeniewski and Myśliwska, 1971). According to Marine Environmental Quality Communiqué of China estuaries, bays and seas abutting big cities are highly contaminated with heavy metals (Zhang et al., 2002). Metals are present in the marine environments as dissolved ions, complexes, colloids, suspended solids and solids in sediment (Larocque and Rasmussen, 1998; Attia and Ghrefat, 2013). This is the reason that, the study of metals in the environment faces many difficulties. Care must be taken when comparing data on metal concentrations in sediment because there may be differences in the methods of sediment classification, the size fraction analyzed, the analytical methods used, which can vary markedly, and the method of data analysis (Duquesne et al., 2006). As mentioned, heavy metals may be mobilized as a result of natural processes as well as by anthropogenic activity. Both sources could be approximately distinguished based on vertical and/or horizontal metal distribution in a given ecosystem. According to Liaghati et al. (2003) vertical profiles are important because they can preserve historical sequence of pollution and, at the same time, enable a reasonable estimation of the background levels and the variations in input of pollutants over an extended period of

* Corresponding author.
E-mail addresses: astel@apsl.edu.pl, AliAst@poczta.fm (A. Astel).

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time. Vertical profiling of beach sediments could be useful to estimate a filtration efficiency of the beach sand.

The Baltic Sea basin ranks among the densely populated areas (140 million people) and is covered by highly industrialized countries (15% of global production). Approximately 60 large cities, 1000 ports and harbors lies on the shores of the Baltic Sea as well as about 200 rivers flow to it. The Baltic Sea is particularly susceptible to an accumulation of pollutants in surficial sediments because it is a semi-enclosed sea (Trojanowski et al., 2001; Belzunce Segarra et al., 2007). High degree of population in the catchment, strong growth of industry and water transport, as well as unfavorable conditions of water exchange cause the Baltic Sea to be heavily polluted. The most serious impacts include shipbuilding, pulp and paper, chemical, pharmaceutical and municipal sewage pollution (Håkanson, 1980). Sandy beaches of the Baltic Sea are characterized by substantial porosity, so they have significant abilities to cumulate pollutants. Sheltered beaches characterized by fine-grained sediments, have much higher capacity of accumulation of pollutants (Wright and Short, 1984; McLachlan et al., 1996). On the contrary, exposed beaches characterized by fine and medium-grained sediments, good oxygenation and high drainage, accumulate lower quantities of pollutants. This is why, an assessment of distribution of metals in vertical and horizontal profiles of Polish beaches is of great importance since more than 60% of the Polish coast comprises sandy ones, both sheltered and exposed. Anthropogenic pollution with heavy metals in the zone of the Polish coast is the topic of great concern since heavy metal pollution of the Baltic Sea has long been recognized as a particular problem and in the past, to a large extent, this has been attributed to anthropogenic import from Poland (Trojanowski et al., 2001, Belzunce Segarra et al., 2007 and Antonowicz et al., 2015). In the process of coastal zone pollution, heavy metals and compounds of phosphorus and nitrogen have the largest share in the Vistula and Oder rivers (Żebrowska-Rasz, 1992).

Despite the fact that a range of studies have been conducted on trace metal distribution in coastal plain sediments universally (Bramha et al., 2014; Jayasiri et al., 2014; Rocha and Vidinha, 2011; Carranza-Edwards et al., 2001; Jonathan et al., 2011, Caredda et al., 1999; Ra et al., 2013, Vallius et al., 2007, Vallius and Leivuori, 2003, Attia and Ghrefat, 2013, Coban et al., 2009 and Özseker and Erüz (2011)) only a few of them were focused on an assessment of profiles of metal distribution in beaches of various anthropogenic impact and various degrees of sheltering. Therefore, the aim of the study was to assess the distribution of alkali (K, Li, Na, Ca, Mg, Ba and Sr) and heavy (Al, Pb, Cd, Mb, Zn, Cu, Ag, Bi, Cr and Mn) metals in vertical and horizontal profiles of three Polish beaches, which differed in anthropogenic impact and degree of sheltering, including seasonal analysis. Moreover, to the best of our knowledge, in the case of Puck location no scientific data concerning metal concentration in beach sand was found.

The study was carried out on around a 130 km segment of the Polish coast where most of Polish sandy beaches are located (Fig. 1).

The samples were collected in Ustka (54°34′N/16°51′E) on the eastern side of the mouth of the Słupia River, in Czołpino (54°43′N/17°14′E) and in Puck (54°44′N/18°24′E). Ustka, Czołpino and Puck are situated in northern Poland. All of them are characterized by beautiful sandy beaches. However, they differ in terms of the degree of anthropogenic impact and the degree of the beach sheltering.

Ustka is the largest sea side resort between Kołobrzeg and Sopot on the Słowińskie Coast. It is located at the mouth of the Słupia River and has served as the port for nearby Słupsk since the 14th century. The mouth of the polluted Słupia River is in the eastern part of the beach. This river carries 15.5 $m^3\ s^{-1}$ of water into the sea, as well as 200 k–300 k $m^3\ year^{-1}$ of natural and anthropogenic sediments (Zawadzka, 1996). Since the end of the 19th century, Ustka has evolved to a popular touristic destination and nowadays it possesses the status of a health resort (Orłowska, 2001). Because of its healthy climate and sandy beaches it is frequently visited by tourists throughout the year. Based on information dated on 2012, the regular number of citizens in Ustka is around 16,300, while during the high season it increases up to 120,000. Many hotels and spas raised along the beach of Ustka, which

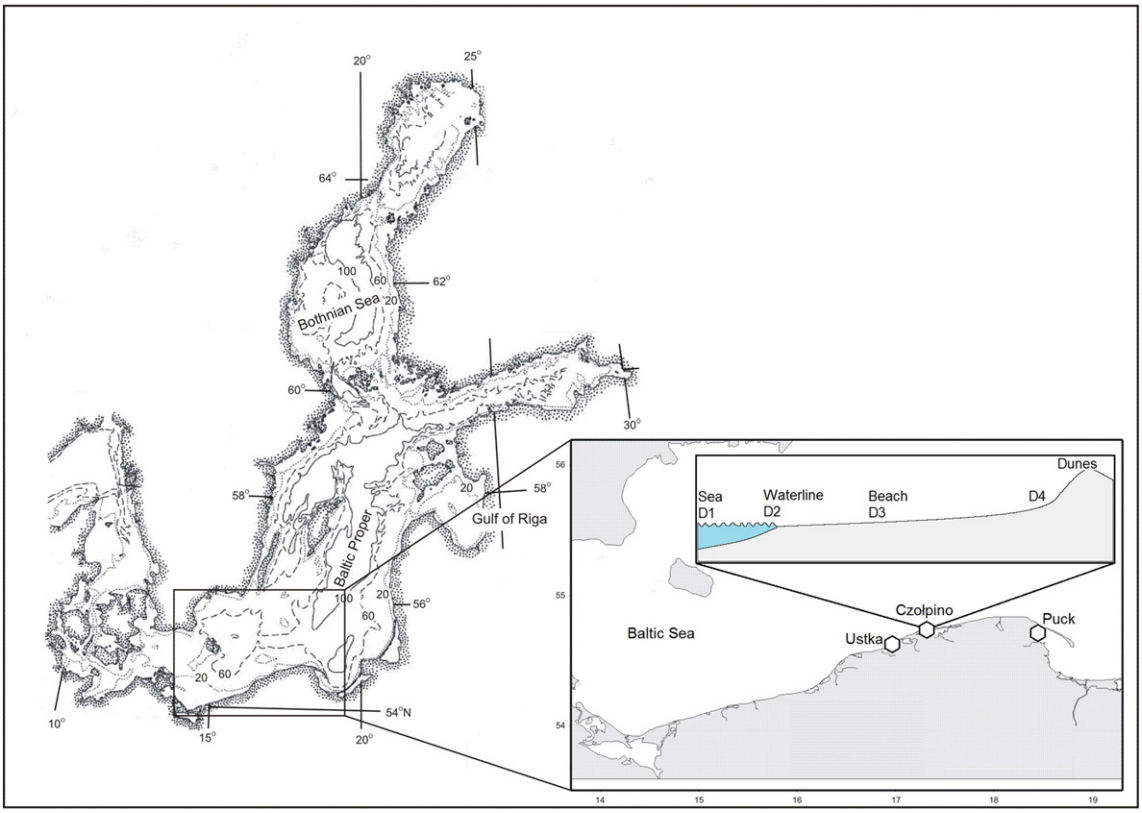

Fig. 1. Location of sampling sites and presentation of the vertical profile of one of the beaches.