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Study of pollutant distribution in the Guaxindiba Estuarine System – SE Brazil

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A B S T R A C T

The Guaxindiba Estuarine System is located in the northeast portion of Guanabara Bay. Despite the location inside an environmental protection zone, the main affluent of the river runs through the extremely urbanized area of the cities of Niterói and São Gonçalo. In order to understand the contamination levels of the estuary, 35 surface sediment samples were collected along the river and estuarine area and analyzed for the presence of heavy metals, PAHs, organochlorated pesticides, polychlorinated biphenyl and other contaminants. The analyzed data revealed a greatly affected environment with respect to most of these substances. The results suggested propitious deposits of contaminants, with high concentrations of organic matter and fine sediment. The levels of heavy metal in the entire estuarine system were high compared with the local background. The total mean concentrations of As, Cd, Pb, Cu, Zn, Hg, Cr and Ni in the surface sediments were: 3.74; 0.03; 19.3; 15.0; 99.0; n.d.; 29.0; and 22.0 mg/kg, respectively, confirming, in certain cases, the high capacity of the environment to concentrate pollution.

1. Introduction

Considered by Pritchard (1967) to be "a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage", estuaries have attracted the attention of scientists due to their major environmental impact. These water bodies receive significant anthropogenic inputs from point and non-point upstream sources, metropolitan areas, tourism, and industries located along the estuarine edges through storm drains. They are also the recipients of: industrial discharge; runoffs from lawns, streets and farmlands; discharge from sewage treatment plants; and atmospheric depositions. Furthermore, this mixing of water with very different salt concentrations and variable physical condition characteristics produces many significant physical, chemical, biochemical, geochemical and bio-geochemical reactions. These have an impact on the aquatic ecosystem (Fazelzadeh et al., 2012), forming multiple unique habitats that support highly diverse communities and provide crucial links to nearby ecosystems (McLusky and Elliott, 2004).

Guanabara Bay receives sewage and garbage from the cities around it. It also receives wastewater from the industrial complex northwest of the bay, which includes oil refineries, fertilizer plants and power stations. All of the wastewater from the different sources is discharged directly or indirectly into the bay. This wastewater contains very large varieties of chemical residues, which disrupt the ecological balance and affect the quality of the water available for human use. Fifteen municipalities are responsible for the release of domestic and industrial sewage into the bay, some of which is discharged untreated into the rivers that run through it. Rivers and sewers also carry urban run-off into the bay, and some of the rivers are known to receive industrial effluent. In addition, large-scale oil refining and transportation activities take place in and around the bay and have been responsible for significant spills in recent years.

Pollutant substances are known to accumulate in the water column or the estuarine bottom sediments (McCain et al., 1988). As a consequence, estuarine sediment contamination is receiving increasing attention from the scientific community, since it is recognized as a major source of ecosystem health stress (Chapman and Wang, 2001; Riba et al., 2002).

The impact of anthropogenic activities on marine environments, especially enclosed systems like Guanabara Bay in Rio de Janeiro, can be determined by measuring various chemical markers, including the nutrients, organic compounds and toxic

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heavy metals that are present in sediment (Audry et al., 2006; Tuncel et al., 2007).

Persistent organic pollutants (POPs) such as organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), polycyclic aromatic compounds (PAHs) and heavy metals are common in many parts of the environment (Hong et al., 1999; Doong et al., 2002; Martin et al., 2003; Fu and Wu, 2006), and may be a hazard to both human health and the environment, even in low concentrations (Brito et al., 2005).

These contaminants are introduced into environments in various ways. In water bodies, for example, and due to their physical and chemical characteristics, they tend to accumulate in bottom sediments. These compounds are strongly attracted to the surface of the particles associated with the organic content of the solid-phase matrix and can be deposited on the surface sediments. Sediment can therefore be used as an indicator of environmental contamination (Dong et al., 2008).

Although numerous countries have long prohibited the use of POPs, these artificial chemicals still persist worldwide (Cleemann et al., 2000; Feng et al., 2003; Verweij et al., 2004; Wurl and Obbard, 2005; Chau, 2006; Katsoyiannis, 2006). Indeed, some of these compounds are still used in tropical and subtropical countries for agricultural and medicinal purposes (Rajendran et al., 2005).

There are very few references in the literature to the use of POPs in developing countries. The first records of the use of organochlorines in Brazil date back to 1946, when insecticides such as HCH and DDT were applied to local crops (MMA, 2006). Since then, large amounts of chlorinated pesticides and PCBs have been used for decades in agriculture, public health and industry. According to Yogui et al. (2010), in the 1980s, regulations were issued prohibiting PCBs and restricting the use of chlorinated pesticides in agriculture, while another regulation in the 1990s prohibited the use of OCs, which was communicated in public health campaigns. At present, however, OCs like lindane can still be used as wood preservatives (Almeida et al., 2007).

In addition to the contamination caused by POPs in sediment from riverine and estuarine areas, the distribution of trace metals can be affected by anthropogenic inputs. Indeed, pollution of the natural environment by heavy metals is a universal problem, because these metals are indestructible. The heavy metals released in the environment as a result of human activities, atmospheric depositions and erosions ultimately enter into aquatic systems. Since these metals are toxic, stable in the environment and have the potential to combine with the nutritive continuum, they are considered to be one of the most significant pollutants of aquatic systems (Desya et al., 2002; Smecka-Cymerman and Kempers, 2001).

The aim of this study is to determine the impact on the Guaxindiba Estuarine System which, despite being located in an environmentally protected zone, is subject to the disposal of pollutants originating from the adjacent watershed due to the lack of sanitation and the presence of various industries in neighboring municipalities. This research also aims to establish a baseline for contaminants in this area, where a major petrochemical complex is currently being built in the watershed that feeds the rivers in the protected zone.

2. Study site

Guanabara Bay is located in southwest Brazil and is considered to be one of the largest bays in the country. The bay is approximately 380 km^2 in size and has a water surface of 328 km^2. The drainage basin measures about 4,000 km^2, with 45 rivers and channels (Kjerve et al., 1997), although just six of these represent 85% of the total discharge of the freshwater bay. All of the rivers in the basin have high slopes in their degree courses, but this characteristic is attenuated when close to the perimeter of the bay, where they have low slopes and meander (Amador, 1997).

The Guaxindiba River basin is located in the northeastern portion of Guanabara Bay, contributing the water and the intake of sediment (Fig. 1). The basin is approximately 144.60 km^2 in size (JICA, 1994), and is occupied by more than a million inhabitants in the cities of Niterói, São Gonçalo and Itaboraí, representing a very concentrated population. The estuarine area is a flat-lying coastal plain with an average elevation of 4.5 m, with quaternary sediments, mainly clays and silts with interbedded sands, which surround these morphological features (Amador and Amador, 1995). The river is enclosed by a well-preserved mangrove area of 135 km^2 in size, where the predominant hydrodynamic energy is principally due to tidal effects.

The main contributors to Guaxindiba River themselves receive large amounts of organic loads of domestic and industrial untreated sewage, with a high degree of deterioration. They are normally used as dumping sites by significant elements of the population who are not served by public urban cleaning. Other potential sources of pollution in the basin include the food processing, pharmaceutical and cement industries beyond the landfill from Morro do Céu (Sisinno and Moreira, 1996). The waters are already heavily polluted when they reach the lower basin, contributing to the degradation of the mangroves and Guanabara Bay.

Recently, this area has received more attention from scientists due to the building of a petrochemical complex in the basin, which will represent a significant source of pollution. Among the main potential effects is the risk of contamination of the groundwater and soil. It is within this context that this paper has been produced in order to understand the actual level of pollution in this area.

3. Methodology

In order to evaluate the actual sediment quality of Guaxindiba River, 35 surface sediment samples were collected in the fluvial and estuarine environment using a stainless steel Van Veen sampler during the summer (January) of 2012. The samples were stored in glass containers that were protected in cooler boxes to preserve them. In the field, we used a Multi-Probe® Mod.YSI85 Blumel to also analyze the water column at each sampling station (surface and bottom) for hydrogen potential (pH), salinity, temperature, and dissolved oxygen. In order to reduce the influence of the physical dynamic over the distribution of the pollution, a tide ruler was installed in the upper riverine sampling station.

The following analyses were carried out on the sediment samples to enable us to understand the local geochemical situation: grain size, total organic carbon (TOC), Kjedahl nitrogen (TKN), total phosphorus content (TP), total heavy metal content (Cd, Hg, Pb, Cu, Cr, Ni and Zn), and As, PCBs, organochlorinated pesticides and PAHs.

A particle size analysis was conducted using a Malvern 2600LC laser analyzer after removing the organic matter. The total organic carbon content was determined with the TOC-5000 organic carbon analysis model from SHIMADZU using a method described by APHA (1995) that was adapted to the samples.

The concentrations of Kjedahl nitrogen and total phosphorus were determined using a methodology described by APHA, AWWA and WEF (1998).

Trace metals and organochlorine compounds were analyzed on freeze-dried sediment, while wet samples were examined for PAH content. Organochlorine pesticides and PCBs were soxhlet extracted and then subjected to an alumina clean-up, silica fractionation and determination with GC–ECD and a capillary column (Smedes and Boer, 1997). PAHs were extracted by saponification