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A combined chemical and biological assessment of industrial contamination in an estuarine system in Kerala, India

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HIGHLIGHTS

- Chemical and biological methods used to study industrial contamination in an estuary
- Structurally diverse organic contaminants identified applying a screening approach
- All relevant organic and inorganic contaminants quantified in water and sediments
- Several contaminant concentrations exceeded toxicity thresholds for benthic species
- Adverse effects on the benthic community in the contaminated area were observed

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ABSTRACT

The Cochin Backwaters in India are part of the Vembanad-Kol system, which is a protected wetland and one of the largest estuarine ecosystems in South Asia. The backwaters are a major supplier of fisheries resources and are developed as tourist destination. Periyar River discharges into the northern arm of the system and receives effluents from chemical, petrochemical and metal processing industries which release huge amounts of wastewaters after little treatment. We investigated water and sediment contamination in the industrial vicinity and at one station further away including organic and inorganic contaminants. In total 83 organic contaminants were found, e.g. well known priority pollutants such as endosulfan, hexachlorobenzene, DDT, hexachlorocyclohexane and their metabolites, which likely stem from the industrial manufacturing of organochlorine pesticides. Furthermore, several benzothiazole, dibenzylamine and dicyclohexylamine derivatives were detected, which indicated inputs from rubber producing facilities. Several of these compounds have not been reported as environmental contaminants so far. A comparison of organic contaminant and trace hazardous element concentrations in sediments with reported sediment quality guidelines revealed that adverse effects on benthic species are likely at all stations. The chemical assessment was combined with an investigation of macrobenthic diversity and community composition. Benthic organisms were completely lacking at the site with the highest trace hazardous element concentrations. Highest species numbers, diversity indices and abundances were recorded at the station with the greatest distance to the industrial area. Filter feeders were nearly completely lacking, probably leading to an impairment of the filter function in this area. This study shows that a combination of chemical and biological methods is an innovative approach to achieve a comprehensive characterization of industrial contamination, to evaluate associated risks for bottom dwelling consumers regarding sediment quality guidelines, and to observe related adverse effects on the benthic community directly in the field.

1. Introduction

India has 16% of the world's population but only 3% of the world's water resources (FAO, 2011). It is the 4th largest producer of agrochemicals, and pesticides played an important role in India's "Green Revolution" that made the country self sufficient in food grain production. Organochlorine pesticides (OCP) by far dominate pesticide manufacturing and endosulfan, dicofol, DDT (2,2-Bis(chlorophenyl)-1,1,1-trichloroethane) and around 33 further formulations are produced at the Hindustan Insecticides Limited facilities at Cochin, Maharashtra and Punjab. Large amounts of pesticide residues yearly reach the Indian coastal ecosystems, and OCP were detected in sediments and aquatic organisms at all trophic levels from rivers and coastal waters (e.g. Mohapatra et al., 1995;

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Senthilkumar et al., 2001). Increased levels of β-hexachlorocyclohexane and dieldrin in blood were attributed to the higher incidence of Parkinson's disease among the North Indian population (Chhillar et al., 2013). Recently, genetic disorders in children and new borns from the vicinity of cashew plantations sprayed with endosulfan in the northern part of Kerala, a state at the southern tip of India, were reported in the newspapers and discussed by the public (e.g. Akhil and Sujatha, 2012).

The principal chemical industries of the Kerala state (~70%) are located near Cochin City at the Chitrapuzha River and the Periyar River banks (at Eloor). The two rivers discharge into the Cochin Backwaters (Fig. 1), a large estuarine system (256 km^2), which are part of the Vembanad-Kol wetlands, a RAMSAR protective area of international importance. The human intervention in the backwaters dates back to 1836 but has accelerated during the last five decades. The booming city of Cochin has a high population density and is one of the 17 major industrial cities of India. There are ~250 industries situated at the Periyar River banks, including Fertilizers and Chemicals Travancore Limited (FACT), Travancore Cochin Chemicals, Travancore Rayon's, Indian Rare Earths Limited, Hindustan Insecticides Limited (HIL), Cochin Refineries, Hindustan Organic Chemicals Limited, Periyar Chemicals, United Catalysts, and Cominco Binani Zinc manufacture. A wide range of chemical products is synthesized including organochlorine pesticides, rubber processing chemicals, paints, pigments, solvents, acids and greases. Furthermore, mercury, zinc, chrome and rare earth elements are manufactured. The processes in the factories include leather tanning, rubber production, production of batteries, and crude oil refining. The industrial facilities take large amounts of water from the Periyar River and in turn discharge concentrated toxic effluents after little treatment (trickling filter technique followed by a clarifier for the removal of sludge or removal of organic matter by anaerobic eubacteria and archaea) (e.g. Nasir, 2010). The Cochin Backwaters also receive untreated effluents (104 billion liters per day) from domestic sectors (CPCB, 1996). In addition, wastes from aquaculture fields (62 km^2), agricultural fields (80 km^2), coconut husk retting yards, fish processing plants, and animal bone processing units have increased the organic pollution of the system (Thomson, 2002).

The continuous discharge of effluents from both domestic and economic sectors that caused eutrophication of the estuarine waters significantly increased the organic carbon content in sediments (four fold in last 4 decades) and affected the distribution of the benthic fauna (e.g. Martin et al., 2011; Akhil et al., 2013). Hazardous element concentrations in sediments increased, especially in the Eloor area (e.g. Priju and Narayana, 2007; Deepulal et al., 2012). Similar areas were reported by previous researchers (e.g. Silva et al., 2011; Ribeiro et al., 2013). Studies on the occurrence of organic contaminants in the Cochin Backwaters are sparse. However, hexachlorocyclohexane, malathion and endosulfan were detected in water and sediment samples which was attributed to their agricultural usage and to direct inputs from a pesticide manufacturing plant at Eloor (Sujatha et al., 1991, 1999; Akhil and Sujatha, 2014).

Until 15 to 30 years ago, the Cochin Backwaters supported a well established endemic fauna with over 90 macrobenthic species and acted as nursery grounds of commercially important prawns and fish (e.g. Menon et al., 2000). In 2005, an inventory recorded 47 species with a decrease of molluscs and an increase of polychaetes compared to earlier studies (Martin et al., 2011). Macrobenthic species numbers and abundances in the industrial vicinity at Eloor were substantially lower compared to downstream stations (Sarala Devi and Venugopal, 1989; Sarala Devi et al., 1991).

Industrial wastewaters may contain very diverse organic compound groups (e.g. Castillo et al., 1999a,b), many of them formerly not known as environmental contaminants as well as trace hazardous elements. The aim of this study was therefore a first comprehensive survey of relevant organic and inorganic contaminants in water and sediments from

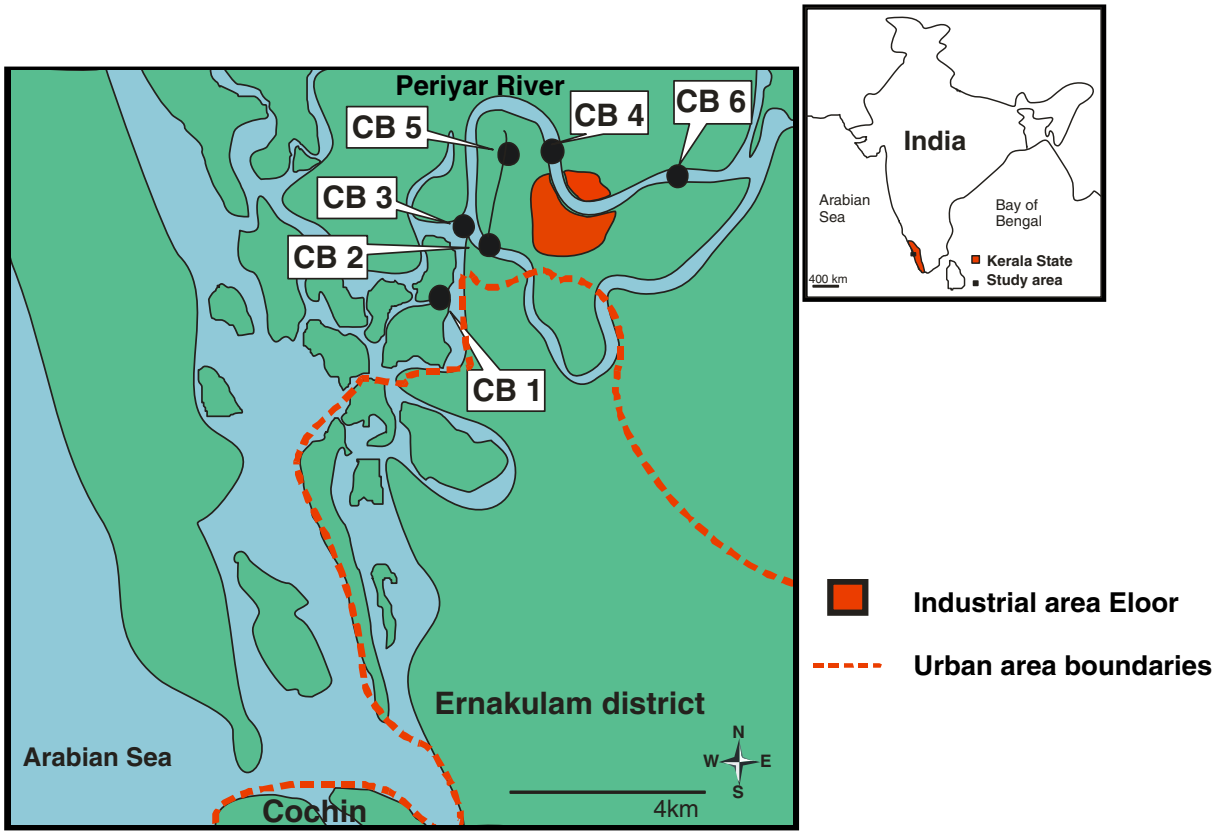

Fig. 1. Schematic overview of the working area which is located in the Cochin Backwaters at the lower reaches of the Periyar River in Kerala State, India. Chemical industries discharge their wastewaters into the Periyar River around the Eloor area.