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A high anthropogenic Sr flux into the Baltic Sea from the Oder River basin and its isotopic record

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The sensitivity of the strontium isotopic composition (87Sr/86Sr) as a versatile tracer for identification of water mixing processes and fingerprinting of natural and anthropogenic inputs of Sr into a river system was investigated in the Oder River basin. The Oder, a middle-size river in central Europe, is characterized by the lowest outflow to precipitation ratio among the rivers flowing into the Baltic Sea; each year, it discharges 17.09 km3 of water only. However, with its very high specific strontium flux (43.13 kg Sr km-2 year-1) the Oder is one of the major Sr contributors to the Baltic Sea. In the catchment area there are strong variations in the Sr isotope composition (from 0.7079 to 0.7134) and the Sr content (from 0.06 to 1.38 mg/L). There is also a general seasonal variability that the waters become more radiogenic and dilute with respect to the Sr in the spring time. In contrast to the majority of Oder's tributaries, the water of the master stream is characterized by a relatively uniform Sr isotope composition, from 0.7100 to 0.7108. The hydrological system of the basin is characterized by very complex mixing relationships, with scenarios that involve Sr contribution from several natural and anthropogenic sources. We found that atmospheric and shallow ground waters, interacting with silicate (mostly Pleistocene glacial deposits) and carbonate bedrocks, constitute the main natural source of strontium. But these are inputs of mine waters, providing Sr from deep-seated Carboniferous, Permian, Mesozoic, and Neogene aquifers, which represent the most critical factors in the Sr budget of the Oder River basin. Predominantly unradiogenic mine waters control the present-day downriver Sr isotope evolution of the Oder and its main tributaries Warta and Noteć. They have radically changed the original, more radiogenic composition of these rivers and are responsible for a significant elevation of the Sr content in the river basin. The influence of other anthropogenic sources, such as fertilizers used in the agriculture, industrial effluents and municipal sewages, is common but of minor importance. The present-day Sr budget of the Oder River basin is temporary and significantly different from that of the preindustrial times.