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European fluxes of anthropogenic gadolinium to ocean: a model based on demography and healthcare databases

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Marine ecosystems are confronted with multiple stressors including historic metal contaminants (e.g. mercury, lead, cadmium) as well as emerging contaminants (e.g. Rare Earth Elements, Platinum Group Elements) due to their persistence and ecotoxicology. Since three decades, the increasing medical use of gadolinium-based contrast agents (Gd-CAs) has contributed to their worldwide dispersion in continental aquatic environments. The stability of these Gd-CAs also leads to their transfer to the ocean without chemical degradation. These compounds are currently being detected downstream of wastewater treatment plants from major cities as well as in the drinking water of many European cities. In order to preserve coastal ecosystems and human health, it thus seems necessary to identify the most contributing European watersheds of anthropogenic Gd (Gd_{anth}) inputs to ocean by identifying Gd-CAs consumption and estimating Gd_{anth} fluxes to the ocean. Better understanding of the geochemical Gd-CAs cycle seem to be key tools for sustainable management.

For this, our study proposes for the first time a model of annual Gd_{anth} fluxes based on the consumption of Gd-CAs, the demography and healthcare databases. This model was validated for France and can be used to estimated that 12 tons of Gd_{anth} were exported to the ocean over the period 2014-2020. The extrapolation of this model to the 48 countries of the European maritime facades allows to estimate annual Gd_{anth} fluxes of 5.3 tons, 2.9 tons, 1.1 tons and 2.9 tons, respectively exported to the Atlantic Ocean, the Mediterranean Sea, the Baltic Sea and the Black Sea for a reference year (2015). We demonstrated that Germany, France and Italy contribute to 40% of the annual European fluxes. Finally, there is a focus on the 2020-year in order to identify the influence of the COVID-19 pandemic on the transfer of these emerging contaminants to the ocean.