QUANTIFICATION OF DIRECT DISCHARGES OF WASTEWATER PHOSPHORUS AND NITROGEN TO THE MEDITERRANEAN SEA

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Abstract
Current nutrient budgets for the Mediterranean Sea do not account for inputs associated with direct wastewater discharges. Here, we demonstrate that the inputs of phosphorus and nitrogen from domestic sources in Mediterranean coastal cities are on the same order of magnitude as inputs from rivers. Population growth, dietary changes and expanded connectivity to sewers are expected to further increase direct wastewater nutrient inputs to the Mediterranean Sea, especially in the southern and eastern regions. Regionally targeted upgrades to tertiary wastewater treatment, combined with enhanced wastewater recycling and banning phosphates from laundry and dishwasher detergents, may be the most cost-effective way to prevent the expansion of coastal eutrophication related to wastewater inputs.

Keywords: Phosphorus, Nutrients, Sewage pollution, Mediterranean Sea

Direct discharges of treated and untreated wastewater can be an important source of nutrients to coastal marine ecosystems. Both treated and untreated wastewater from coastal cities are discharged directly into the Mediterranean Sea (MS), either at the surface or via submarine pipes (referred to as direct discharges in the following). Wastewater inputs pose a threat to the vulnerable ecosystems of the MS and are likely to increase in the near future. Of particular concern are algal blooms within the coastal zone of the MS linked to discharges of wastewater. Nonetheless, current nutrient budgets for the MS do not include direct wastewater discharges of phosphorus (P) and nitrogen (N).

Here, we use an empirical formula [1] to estimate the spatially distributed annual inputs to the MS of P and N associated with direct domestic wastewater discharges from coastal cities exceeding 2000 inhabitants:

$$D_{P,N} = P,N_{capita} * pop * f_c * (1\text{-}f_R)$$

where $D_{P,N}$ is expressed in units of mol yr^{-1}, P,N_{capita} is the annual P or N domestic wastewater load per inhabitant (mol $capita^{-1}$ yr^{-1}), *pop* is the population of the city, f_c is the fraction of the city's population connected to the sewer system, and f_R is the fraction of P or N removed from the wastewater stream in the city's wastewater treatment plants, which is dependent on the type of treatment – primary, secondary or tertiary.

$D_{P,N}$ is calculated for each individual city using data from surveys collected by UNEP [2,3] and supplemented with estimates for discharges from Gaza and Cairo into Lake Manzalla. These estimates are representative of the first few years of the 21st century.

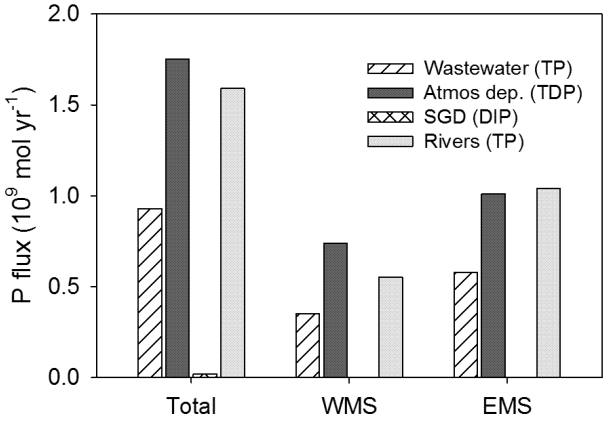

Fig. 1. Inputs of total phosphorus to the Mediterranean Sea: 2003 direct domestic wastewater (this study) versus atmospheric deposition (atm. dep.) [5], submarine groundwater discharge (SGD) [6] and 1998 riverine discharges [4]. WMS = Western Mediterranean Sea, EMS = Eastern Mediterranean Sea, TP= total phosphorus, TDP = total dissolved phosphorus, DIP = dissolved inorganic phosphorus.

According to our best estimates, in 2003, direct wastewater inputs amounted to $0.9x10^9$ mol P yr^{-1} and $15x10^9$ mol N yr^{-1} for the entire MS. They are on the same order of magnitude as 1998 riverine input fluxes to the entire MS of $1.6x10^9$ mol P yr^{-1} and 77 $x10^9$ mol N yr^{-1} [4] (Fig. 1). In addition wastewater P discharges are comparable to atmospheric deposition of total dissolved P [5], and an order of magnitude greater than estimates of the freshwater dissolved inorganic P delivered by submarine groundwater discharge [6]. Although relatively less significant, wastewater N inputs are still on the same order of magnitude as other external inputs. Thus wastewater discharges are an important, but so far largely ignored, source of P and N and should be included in biogeochemical budgets for the MS.

Wastewater inputs are projected to increase significantly in the future across the Mediterranean region. Primary productivity in the MS is P limited and hence we calculate changes in P inputs from wastewater discharges in 2050 relative to 2003. Population growth, higher per capita protein intake and increased connectivity to the sewage system increase 2050 direct discharges of P from wastewater by 272, 181 and 41% for South, East and North Mediterranean countries respectively if no mitigation occurs. To reduce 2050 inputs to below 2003 values all wastewater discharged to the sea is required to have tertiary treatment, but this would come at an additional estimated cost of over €2 billion yr^{-1}. Other and more realistic mitigation measures include enhanced recycling of treated wastewater and legislation to curb the use of P in laundry and dishwasher detergents, although these measures alone will not entirely offset rising domestic wastewater P loads in East and South Mediterranean countries. Management of coastal eutrophication may therefore best be achieved through targeted tertiary treatment in coastal areas susceptible to eutrophication at a predicted additional cost of over €500 million yr^{-1} together with enhanced recycling of domestic wastewater and implementation of detergent legislation throughout Mediterranean countries.

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