



Fast increases in river pollution from sewage: a global trend

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The sixth Sustainable Development Goal of the United Nation calls for clean water. Clean water is a worldwide issue because many fresh water resources like rivers are polluted, and often by more than one pollutant. Water pollutants include nutrients (nitrogen, phosphorus), micro-plastics, chemicals (e.g., triclosan) and pathogens (e.g., *Cryptosporidium*). These pollutants decrease the availability of clean water for agriculture, domestic and industrial uses, and impact society and ecosystems via, for example, human diseases and fish kills. Important sources of river pollution are human activities such as agriculture and urbanisation. Urbanisation may become more important in the future as around two-thirds of the world population are estimated to live in urban areas in 2050.

In this study, we analyse inputs of pollutants to rivers from sewage systems for the past (2000), presents (2010) and future (2050). Our analysis is for around 10,000 river (sub)basins worldwide. We quantify inputs of the following pollutants: nitrogen (N), phosphorus (P), *Cryptosporidium* (Crypt), micro-plastic (MP) and triclosan (TSC, hormone disruptor). N, P and Crypt in human waste enter sewage systems via centralized systems. MP enters sewage systems from personal care products (PCP), household dust, laundry and car tyres. TSC is contained in PCP as an antibacterial agent and thus it enters sewage systems with other pollutants. Inputs of the pollutants to rivers from sewage systems are quantified based on existing modelling approaches for N and P, Crypt, MP and TSC that also provided required inputs. These calculations are done as a function of pollutant excretion in human waste (N, P, Crypt) or consumption rates (MP, TSC) and the number of people connected to sewage systems, corrected for pollutant removal during treatment. Population growth and urbanization estimates for 2050 are based on the storyline of a Shared Socio-economic Pathway (SSP 1).

Results show fast increases in sewage inputs of pollutants to rivers between 2000 and 2050. In 2000, sewage was a source of pollution in about 50% of the rivers in the world. This percentage was higher for Europe and for some rivers in North America and South Asia for most of the pollutants. By 2010, sewage was a source of pollution in almost all rivers worldwide. This increase has to do with the fact that more people became connected to sewage systems in 2010. This is a result of urbanization: more cities with sewage systems. As a result, more waste was collected by centralized sewage systems in 2010 than in 2000. However, treatment efficiencies did not increase enough to reduce pollutants to rivers in 2010. An exception is some rivers in Europe and North America for which we calculated generally lower inputs of the pollutants in 2010 than in 2000. By 2050, many rivers in the world may be more polluted from sewage. This is because of rapid urbanization, while treatment will be not efficient enough to remove pollutants in urban waste. Our study provides hotspots for river pollution worldwide. This information can help to prioritize monitoring programs and pollution reduction strategies for urban areas.