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# Drivers of contaminant levels in surface water of China during 2000–2030: Relative importance for illustrative home and personal care product chemicals

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ABSTRACT

Water pollution are among the most critical problems in China and emerging contaminants in surface water have attracted rising attentions in recent years. There is great interest in China's future environmental quality as the national government has committed to a major action plan to improve surface water quality. This study presents methodologies to rank the importance of socioeconomic and environmental drivers to the chemical concentration in surface water during 2000–2030. A case study is conducted on triclosan, a home and personal care product (HPCP) ingredient. Different economic and discharge flow scenarios are considered. Urbanization and wastewater treatment connection rates in rural and urban areas are collected or projected for 2000–2030 for counties across China. The estimated usage increases from ca. 86 to 340 t. However, emissions decreases from 76 to 52 t during 2000–2030 under a modelled Organisation for Economic Co-operation (OECD) economic scenario because of the urbanization, migration and development of wastewater treatment plants/facilities (WWTPs). The estimated national median concentration of triclosan ranges 1.5–8.2 ng/L during 2000–2030 for different scenarios. It peaks in 2009 under the OECD and three of the Intergovernmental Panel on Climate Change (IPCC), A2, B1 and B2 economic scenarios, but in 2025 under A1 economic scenario. Population distribution and surface water discharge flow rates are ranked as the top two drivers to triclosan levels in surface water over the 30 years. The development of urban WWTPs was the most important driver during 2000–2010 and the development of rural works is projected to be the most important in 2011–2030. Projections suggest discharges of ingredients in HPCPs - controlled by economic growth - should be balanced by the major expenditure programme on wastewater treatment in China.

## 1. Introduction

Water contamination can be harmful to human and ecosystem health. Emerging contaminants, such as pharmaceuticals, home and personal care products (HPCPs) have raised growing concerns (Boxall et al., 2012; EPA, 2017). Reducing untreated wastewater and protecting aquatic ecosystems are targets of the Sustainable Development Goals set by the United Nations to be reached by 2030 (Hering et al., 2016). China is a country with major challenges of water quality and availability, including: the size and diversity of the country and its rivers; the population size and migration; rapid economic growth, with increased industrial, agricultural and domestic demands for usable water and the effluents that these activities generate. The Chinese Government therefore developed an 'Action Plan for Water Pollution Prevention' in mid-2015 (MEP, 2015a), which is laid out in the national 13th 5-Year Plan (CPGC, 2016). However, in order to make rational, effective and informed decisions which will improve water quality, there is an urgent need for a methodology to identify the potential key drivers to affect the level of contaminants in surface water, especially for those anthropogenic-source contaninants. The results could improve and inform understanding, policy and decision-making.

Socio-economic activities and environmental changes have affected water quality in China during the remarkable development over the past decades (Gleick, 2008–2009). Ingredients in HPCPs represent an

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interesting case, because they are closely linked to socio-economic activities and as trace organics they could be markers of sewage and anthropogenic-source ingredients (Gasser et al., 2010; James et al., 2016). Some HPCPs are relatively poorly studied so far and have attracted increasing interest in recent years (Boxall et al., 2012) such as UV filters and parabens, yet some of them are abundant and being considered for environmental limits and more controlled usage, such as triclosan and triclocarban. HPCPs are diffusively discharged in wastewaters. Their consumption increased between ~40–~800% in China during the economic boom between 2000 and 2012 (Euromonitor, 2015); however, China also increased its wastewater treatment capacity by about 8-fold during the same period (Supporting Information (SI) Fig. S1), due to several factors (i.e. rising urbanization, compliance with discharge standards) (MHURD, 2013), potentially counterbalancing the potential release of HPCPs to the environment. Other marked societal and infrastructure trends have occurred and will continue in future. Population growth and migration and rapid urbanization progress (Yang, 2013) across China make the change of ingredient usage and release more complex geographically. Changing discharge flow, linked to environmental and infrastructure changes, also affects the dilution of chemicals in surface water. These factors have changed/are changing in a way that could be strongly impacting the concentrations and distributions of chemicals in surface water and the water quality (Zhu et al., 2016; Zhu et al., 2014).

This study was therefore conceived to develop a modelling approach, to explore the potential influence of several key drivers on past, present and future chemical surface water concentrations in China. We address several drivers which will influence ingredient usage, release and loading in aquatic systems, namely economic development as Gross Domestic Product (GDP), population, urbanization, wastewater treatment capacity and discharge flow rates, to estimate temporal changes in water concentrations. Measurements of pharmaceutical and HPCP ingredients have only become available for a limited number of regions in recent years in China. We chose triclosan as an example ingredient in the calculation as it is well studied and there are more monitoring data available than other ingredients for model validation (Zhu et al., 2016). It enters the aquatic environment diffusively, primarily from domestic wastewaters. Scenarios considered here take account of main drivers discussed above to: (1) model usage, emissions and concentrations in surface water of triclosan in China as an example ingredient between 2000 and 2030, assuming that it continues to be used in HPCPs in that period; (2) identify and rank the key drivers affecting surface water concentrations. This approach has not been used before, but we believe it can be adapted and applied to a range of chemicals from anthropogenic sources with different usage/release scenarios in future, using the base data and modelling tools assembled here.

## 2. Methodologies and approaches

### 2.1. Ingredient usage under five economic scenarios

OECD (Organisation for Economic Co-operation) per capita GDP (OECD, 2014) was found to significantly correlate ($R^2 > 0.88$) to sales volumes (tonnes) of HPCP categories which contain triclosan (SI Table S1 and Fig. S2) (Mintel, 2014) in the Chinese market for 2000–2019 (Euromonitor, 2015). As seen in SI Fig. S2, most correlations fit linear regression, except those for shampoo, bleach/disinfectant and all-purpose surface care products (SI). Besides these fast moving consumer HPCP categories in Table S1, triclosan is also used in plastic materials, textiles, surface of medical devices, etc. These usages and releases were not taken into account in this study as they are expected to be a small proportion of the total (Euromonitor, 2015; SCCS, 2010). In addition, emission pathways are complex depending on how these materials are disposed of; and triclosan leaching from these materials is likely to be slow (SCCS, 2010) compared to the daily used HPCP categories.

Based on above regressions, the annual sales volumes of HPCP categories which contain triclosan were extrapolated for 2011–2030 under five economic scenarios, i.e. one from OECD future GDP outlook (OECD, 2014) and four predicted by the Centre for International Earth Science Information Network (CIESIN) under four IPCC marker scenarios (A1, A2, B1 and B2) (CIESIN, 2002). OECD is an authorivative economic institution that could provide potentially reasonable economic outlook as reference. IPCC scenarios consider extreme and moderate conditions, which have been widely used in ecology or energy relevant studies. For the feature of the five economic scenarios and their comparison see SI and Table S2. The two 'A' economic scenarios were extreme; the two 'B' scenarios and the OECD projection are moderate (SI Fig. S3). The historical sales volume for 2000–2010 was directly taken from the Euromonitor database (Euromonitor, 2015). Products sold in a year were assumed to be consumed within the same year. Triclosan usage was, therefore, estimated from product sales volumes, the inclusion level in products and the percentage of product variants (Mintel 2014) that contain triclosan for all product categories (Eq. (1) in SI). The product categories and triclosan inclusion level (0.3%) (Hodges et al., 2012) were assumed identical during 2000–2030. Based on the usage, emission and surface water concentrations were estimated under these five economic scenarios with the projection of other main drivers described below.

It is assumed there will be no bans or elimination of triclosan in this study till 2030 in China. However, future replacement or reduction of ingredient use is possible due to potential government restrictions or if it is phased out by industry.

### 2.2. Population and urbanization

The gridded (~1 km) Chinese population count and density were projected by CIESIN for the years 2000, 2005, 2015 and 2020 (CIESIN, 2016a, 2016b) and by another study for 2030 (Feng and Qi, 2016; Qi et al., 2015). For the year 2010, to keep identical to our previous study (Zhu et al., 2016), data projected by Landscan (Landscan, 2010) was used. The urban population was identified by the population density > 5000 (CIESIN, 2011) cap/km$^2$ for 2030 and > 1000 cap/km$^2$ for the other 5 years. 5000 cap/km$^2$ was suggested in some publications but found too high on the population data by CIESIN. Therefore, 1000 cap/km$^2$ was additionally used in this study, which could result in more reasonable results since they are verified with the census of the national urban population (CNSTATS 2000–2015) (SI Fig. S4) and the predicted potential annual urban population growth rate for future China (ca. 2%). The projected urban expansion from 2000 to 2030 is shown for every five years in Fig. 1. To fill the population data gaps between every two adjacent years with existing projected data (e.g. years between 2000 and 2005), it was assumed that the annual change rate of urban and rural population would be steady between the two years. The projected population was applied to the five economic scenarios to spatially allocate ingredient usage and to estimate population connectivity to wastewater treatment facilities installed in rural and urban areas during 2000–2030.

### 2.3. Wastewater treatment connection rates

The records for estimating the wastewater treatment connection rates, i.e. the proportion of population connected to wastewater treatment, could be found from the yearbook for 2002–2013 (covered by light green shade areas in Fig. 2A) for urban areas and for 2008–2013 for rural areas for China (MHURD, 2013). The wastewater treatment connection rate was estimated by total wastewater discharge volumes dividing those volumes treated for individual cities. The average of city level wastewater treatment connection rates for urban areas increased from 40% to 89% between 2002 and 2013; the average of provincial level wastewater treatment connection rates for rural areas increased from 2.5% to 6.4% between 2008 and 2013 (Fig. 2A) (MHURD, 2013). Nationally, urban wastewater treatment plants (WWTPs) developed