cancer due to THM exposure from consuming bottled water in Barcelona. Our analysis highlights several critical data gaps and methodological challenges in quantifying integrated health and environmental impacts of drinking water choices.

1. Introduction

Bottled water consumption has sharply increased in the last years worldwide (Rodwan, 2018). This global trend is partly explained by subjective factors like risk perception and organoleptics (Doria et al., 2009), lack of trust in public tap water quality (Saylor et al., 2011), and marketing by the bottled water industry (Gleick, 2010). The recent increase in bottled water use globally has been driven by a sharp increase in demand in low- and middle-income countries (LMICs), despite parallel increases in access to piped water in some countries (Cohen and Ray, 2018). However, bottled water consumption involves much higher environmental impacts compared to public drinking water supply (Garfí et al., 2016).

Plastic production processes are responsible for non-renewable resource depletion and for the emission of harmful pollutants (e.g. greenhouse gases, particulate matter) into the environment. Even in the case of high-energy consuming technologies for drinking water treatments, tap water always shows better environmental performance in terms of global warming potential, compared to bottled water (Fantin et al., 2014). The growing use of bottled water also contributes to the sharp increase of plastic debris worldwide (Geyer et al., 2017), including microplastics (Brandon et al., 2019). Plastic debris are the most serious problem affecting the marine environment (UNEP, 2014) and also affect terrestrial ecosystems (de Souza Machado et al., 2017). The accumulation and fragmentation of plastics (Barnes et al., 2009) contributes to the ubiquitous presence of micro- and nanoplastics as an emerging contaminant in the food chain (Van Cauwenberghe and Janssen, 2014) and the water cycle, including drinking water (Schymanski et al., 2018).

Both municipal and bottled water may contain chemicals of health concern. However, research on drinking water quality has mainly focused on public supply, and less data are available on contaminants in bottled water. Current knowledge indicates that concentrations of disinfection by-products such as trihalomethanes (THMs) are usually higher in municipal vs. mineral bottled water (Font-Ribera et al., 2010). However, bottled water may contain higher levels of endocrine disruptors (Pinto and Reali, 2009; Real et al., 2015; Wagner et al., 2013; Wagner and Oehlmann, 2009) and microplastics (Koelmans et al., 2019) that may originate from plastic containers. In addition, inappropriate handling of bottled water can lead to microbial growth (Raj, 2005), and faecal contamination has been detected in bottled water, particularly among LMICs (Williams et al., 2015). THMs are of particular concern because of widespread exposure in countries where disinfection of drinking water is a common practice. THMs are volatile and skin permeable, thus inhalation and dermal contact are relevant exposure pathways in water-contact activities, beyond water ingestion (Ashley et al., 2005). Virtually the entire population is exposed through inhalation and dermal contact while showering and bathing, in addition to ingestion, and long-term exposure has been consistently associated with increased bladder cancer risk, a cancer site primarily affecting adults. Among the long list of health-relevant chemicals that can be present in drinking water, THMs are an attractive focus for health impact assessment because of widespread exposure in the population through multiple exposure routes (Villanueva et al., 2015), consistent epidemiological evidence showing a link between long-term THM levels as a marker of exposure to disinfection by-products and increased bladder cancer risk (Cantor et al., 2010; Costet et al., 2011), and available exposure-response relationship (Costet et al., 2011; Villanueva et al., 2004).

The city of Barcelona, Spain, is supplied by different water sources and treatment plants and has been characterized by high THM levels in the past in some water supply zones (i.e. areas receiving water from common treatment plants, thus having homogenous quality). Concentrations of THMs were drastically reduced after technological improvements in the drinking water treatment plants in 2009. Annual average concentrations of THMs were above 100 μg/L in some areas prior 2009, decreasing to ≈50 μg/L after 2009 (ASPB, 2012). Barcelona is also characterized by high levels of bottled water consumption. Bottled water was the primary source of drinking water among 50% of the population in 2006 (Font-Ribera et al., 2017), increasing to 60% in 2016 (ASPB, 2019) despite the improvements in the quality of the public drinking water supply. Most bottled water sold in Spain is mineral water (Heras, 2018), defined as spring water with a constant composition of minerals, intended for human consumption in their natural state and bottled at source (EC, n.d.). From this point forward bottled water consumption in Barcelona refers to mineral water.

While Life Cycle Assessment (LCA) of water treatment processes and health impact assessment (HIA) have been conducted previously in the context of drinking water treatment options (Ribera et al., 2014), to our knowledge, no previous study has linked the two methodologies to provide a comprehensive, quantitative assessment of the health and environmental tradeoffs associated with individual drinking water choices. We address this gap by estimating the health and environmental impacts under four drinking water consumption scenarios for the city of Barcelona, which we selected as a case study based on availability of data. We aimed to estimate the burden of bladder cancer in the local population attributable to THM exposure and the environmental impact linked to the production of drinking water.

2. Methods

2.1. Drinking water consumption scenarios

Drinking water consumption patterns in the Barcelona population were ascertained from the Barcelona Health Survey (BHS) conducted in 2016–2017 by the Barcelona Public Health Agency (Bartoll et al., 2018). Briefly, 4000 district-stratified Barcelona residents (400 per district, 10 districts) representative of the general population, were randomly sampled and interviewed at their residence. Participants answered a questionnaire covering self-perceived health and health risk factors, including drinking water consumption patterns through the closed-ended question "*How frequently do you drink tap water without filtering, filtered tap water, bottled water, and water from natural sources*?" Answer options included: *usually, occasionally, never*. The survey did not collect data on the type of filter, that could include any domestic device such as countertop pitchers with activated carbon, under the sink reverse osmosis units, or faucet mounted filters (March et al., 2020).

Our goal was to estimate the burden of bladder cancer attributable to total THM exposure that could be avoided by changing drinking water source among the adult (≥20 years old) population of the city of Barcelona (1,349,570 inhabitants ≥20 years old in 2017, INE, 2018) and link each scenario with associated environmental impacts. We considered three sources, following the BHS: tap water with no filtration, filtered tap water using a domestic device, and bottled mineral water. We defined the drinking water consumption scenarios (S1–S4) with variable drinking water source as follows: