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Bridging the Regulatory Gap: Estrogen Hormones in Aquatic Systems and Drinking Water

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Highlights:

- The presence of hormones in rivers can lead to harm to aquatic ecosystems and deterioration of water quality.
- Hormones are not effectively removed by conventional water treatment methods and may pose a risk to human health.
- Water and wastewater treatment plants capable of removing hormones will likely also remove a broad spectrum of other emerging pollutants.

Keywords: Water Quality Legislation; Regulatory Framework; Emerging Pollutants;

INTRODUCTION

Among the emerging pollutants, Estrogen Hormones (EH) have been identified as compounds of great concern because they are biologically active, have a long biological half-life, and are recalcitrant with low biodegradability (Berne & Levy, 2009). The EH of most concern, from environmental and human health points of view, are Estrone (E1), Estradiol (E2), and Ethinyl Estradiol (EE2) (Nazari & Suja, 2016). E1 and E2 are produced naturally by mammals but can also be synthesized by the pharmaceutical industry, as can EE2. These hormones are indispensable for the proper functioning of organisms (human and animal) and are widely used in medicine as treatments for diseases, disorders, and hormonal readjustments. Consequently, these compounds are commonly detected in both wastewater and water bodies, posing risks such as feminization in aquatic organisms, as alongside declines in fertility and the occurrence of malformations in juvenile individuals (Adeel et al., 2017; Vilela et al., 2018).

These pollutants accumulate in domestic, industrial, hospital, aquaculture and agricultural effluents and are difficult to remove by conventional wastewater treatment plant (WWTP) processes. If these compounds are present in rivers and this water is used for public supply, these compounds are also not completely removed by conventional water treatment plant (WTP) processes (Vilela et al., 2018).

For this reason, these estrogenic hormones (EH) will be the target compounds of this work. It is important to note that while these compounds are indispensable in medicine and the proper functioning of human and animal organisms, they will continue to be present in effluents. However, their presence in inadequate concentrations in water bodies and treated water poses significant risks to human and environmental health. Therefore, it is crucial to establish legislation that limits their concentrations in these systems.

To this end, a thorough literature review will be conducted to understand: i) the steps that have already been taken to include these compounds in the list of those required for water and effluent treatment; ii) the reasons why these compounds remain unregulated; and iii) how to formulate safe, robust, and enforceable regulations for these compounds.

METHODOLOGY

This study constitutes a critical literature review. The methodology used for gathering information and references was the Boolean method adapted by Saadatpour & Albert (2013), which involves searching for works in online databases, such as Science Direct, Web of Science, Scopus, regulatory agency documents, and legal databases. After this process, the articles were selected by relevance, resulting in a database. From the database we obtained: i) the steps that have already been taken to include these compounds in the list of those required for water and effluent treatment; ii) the reasons why these compounds remain unregulated; and iii) how to formulate safe, robust, and enforceable regulations for these compounds.

RESULTS AND CONCLUSIONS

In the European Union context, estrogenic hormones (E2 and EE2) were only mentioned in 2012 through the COM (2011) 876 proposal, which suggested threshold values for surface freshwater. However, this proposal was rejected, and E2 and EE2 were added to the priority substances list via Directive 2013/39/EU, but only for monitoring purposes, without the imposition of detection limits. The rejection was due to the high costs associated with structural and process upgrades required at wastewater treatment plants to meet the discharge limits (Cunha et al., 2016). Nevertheless, studies suggest that more advanced treatment processes would allow for the removal of a broader range of substances, thereby improving water quality and reducing downstream water treatment costs (Gilbert, 2012; Owen & Jobling, 2012). Later, with the implementation of Directive 2018/840/EU, which remains in effect, detection limits were established for monitoring equipment, with 0.035 $ng.L^{-1}$, 0.4 $ng.L^{-1}$, and 0.4 $ng.L^{-1}$ for EE2, E2, and E1, respectively (EU, 2018).

Similarly, in the United States, the Contaminant Candidate List (CCL) was established to monitor and quantify pollutants identified by the scientific community as potentially dangerous, whose concentration limits are not regulated, providing guidance to legislative bodies. The first CCL was proposed in 1998 and estrogenic hormones were only included in the third edition (CCL 3) (US EPA, 2009). In CCL 4, E2 and EE2 remained on the list as contaminants of interest (US EPA, 2016), but in CCL 5, currently in effect, only EE2 continues to be listed as a contaminant of interest (US EPA, 2022).

In Australia, there has also been concern about regulating these compounds. The "Australian Guidelines for Water Recycling" highlighted this issue and proposed reference values for the presence of estrogenic hormones in drinking water. The proposed threshold values were 0.03, 0.175, and 0.0015 $\mu g.L^{-1}$ for E1, E2, and EE2, respectively (NWQMS, 2008). But these values are not part of the legislation yet.

In contrast, in Singapore, despite the absence of specific legislation, the sanitation company NEWater follows strict potable water standards, including detection limits for emerging pollutants since 2000. For estrogenic hormones, the threshold values for E1, E2, and EE2 in drinking water are set at 0.001 $\mu g.L^{-1}$ each. Since these are not the only estrogens present in recycled water, a total threshold of 0.003 $\mu g.L^{-1}$ for all estrogens has also been established (WHO, 2017), although these values are not yet part of formal legislation.

In Brazil, current legislation does not establish limits for these compounds in wastewater discharge or drinking water supplies, nor does it mandate monitoring in water bodies. However, the trend is toward increasingly restrictive regulations (Cunha et al., 2016). Additionally, Bill 4541/2020 stipulates that the Executive Branch establish limits for estrogen concentrations in water and sewage systems. These limits should be set below concentrations harmful to human and environmental health; however, the bill does not specify these thresholds. PL 4541/2020 was accepted by the Environment and Sustainable

Development Commission on March 12, 2021, but has not yet been put to a vote (Brazil, 2020). Similarly, Bill 260 of 2024 proposes guidelines for the removal of persistent organic pollutants, endocrine disruptors, and microplastics in drinking and wastewater. This bill also does not specify reference values or list which pollutants within each category should be regulated, and it has yet to be voted on in the Senate (Brazil, 2024).

For laws to be enacted, there must be a so-called "usage and custom" concerning the subject being legislated. This refers to the everyday existence of the issue and the awareness of the parties involved (Plácido & Silva, 1996). In the context of estrogenic hormones (EH) and other micropollutants, this means evaluating the presence of these compounds in the environment, understanding the potential harm they cause, and raising awareness among potential polluters about the necessity of these regulations.

This process involves three key types of political instruments: a) public support, as citizens are both potential polluters and influential in regulatory decisions through electoral mechanisms; b) market analysis, with subsidies or taxes used to control pollution by companies; and c) evaluation of production and consumption chains, ensuring that legislative and executive bodies fully understand the lifecycle of these compounds, from manufacture to consumption, enabling the creation of a robust, enforceable law (Metz & Leifeld, 2018; Tosun et al., 2020).

It is essential that environmental policies be accessible and gain popular support, as decision-makers depend on their constituents' approval of the proposed regulations (Tosun et al., 2020). Environmental education is a crucial tool for fostering public awareness (Battaini & Sorrentino, 2018), informing the population about the presence of these compounds in the environment, their potential impacts on human and environmental health, and the need to advocate for public policies on this issue.

Public and private sector support is also critical for compliance with legislation (Ingold et al., 2016). Low levels of support can result in non-compliance, rendering the measures ineffective and generating additional costs due to the need for sanctions and rigorous monitoring (Harring et al., 2017).

The formulation of regulations on this matter should engage multiple stakeholders, including potential polluters, public support, and government bodies. It is crucial that everyone comprehends the rationale behind these regulations and that the guidelines establish safe yet practical and enforceable concentration limits.

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