What Actions Should Canada Take to Address the Issue of Contaminants of Emerging Concern in Water?

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Executive Summary: Meeting the growing demand for access to clean, safe, and reliable water in Canada requires addressing not just traditional water contaminants, but also contaminants of emerging concern (CEC). CECs cause deleterious effects on human health, and yet Canadian drinking water standards currently exclude a majority of them from regulatory control. To ensure long-lasting access to safe drinking water, this paper aims to present policy recommendations for the Canadian legislature including a detailed analysis of the cost implications, feasibility, and ease of implementation of each option using the EHER (environment, health, economy, and reputation) criteria. We recommend a collaborative solution to CECs management which involves academic research funding to comprehensively analyze the risks of CECs and strategies for their removal as well as regulations controlling CECs levels in water streams through reviewed standards and guidelines.

I. Introduction

The world at large is plagued by environmental challenges occasioned by widespread industrialization and technological advancement, through which a variety of synthetic chemical contaminants are introduced into the environment (Goldstein 2017). Advanced industrial activities that use newer processes and chemicals have increased concerns among researchers, government agencies, and policymakers regarding a new class of pollutants, known as contaminants of emerging concern (CEC), and their emerging effects on water resources (Naidu et al. 2016a). This class of pollutants can bioaccumulate, they are persistent and bioactive, and they are resistant to most of the conventional treatment methods (Pereira et al. 2015). These contaminants, when introduced into the environment, usually end up in water bodies, and could have chronic effects on humans, thus posing a long-term risk (Pereira et al. 2015). The quality of drinking water is therefore under threat due to these emerging contaminants (Abioye et al. 2024). Despite the emerging evidence regarding the chronic health effects of this new class of contaminants and their prevalence in Canadian surface water, there are limited proactive measures by the government at all levels toward addressing the growing concerns (Gilbride et al. 2021). This analysis paper is aimed at advising the Canadian government on science policy-based solutions to address CECs and their effect on the environment.

CECs are chemical compounds that were previously thought to not have any significant effect on the quality of drinking water (Abioye et al. 2024). Previously available technology was not able to easily detect them, however, current technologies have allowed for their increasing detection in surface water. Furthermore, most of these contaminants are left unregulated (Gilbride 2020). CECs are ubiquitous in water and wastewater streams. Some examples include per- and polyfluoroalkyl substances (PFAS), Bisphenol A (BPA), polycyclic aromatic hydrocarbons (PAHs), pharmaceuticals and personal care products (PPCPs), microplastics, and illicit drugs. According to Health Canada, while

Canadian drinking water is free of the majority of PAHs and polychlorinated biphenyls, out of all the other numerous emerging contaminants available, PFAS is the only pollutant recently considered by the Canadian government in drinking water guidelines (Health Canada 2022). Table 1 describes some of the most common emerging contaminants, their pathways into the environment, and their effects on humans and the aquatic environment.

The CECs have several pathways through which they enter bodies of water. The major pathway is through industrial discharges, such as pharmaceuticals and other industrial chemicals. Additionally, pharmaceuticals get into the water through excreted metabolites (from urine and feces) via the sewage stream (Abdel-Shafy and Mohamed-Mansour 2013). As conventional wastewater treatment plants are limited in the removal of this kind of contaminant, pharmaceuticals eventually contaminate bodies of water and thus are present in drinking water. Likewise, other CECs such as BPA enter the environment through effluents resulting from the manufacturing of epoxy resins, beverage cans, and plastics (Li et al. 2015). PFAS are introduced into the ecosystem through industrial activities involving the production of consumer products such as carpets, clothing, non-stick pans, and food packaging. Anthracene, a PAH, gets introduced into water bodies through wood preservatives and dye-production effluents (Abdel-Shafy and Mansour 2016). More examples of contemporary CECs include pesticides, flame retardants, plasticizers, and surfactants (Pereira et al. 2015).

With advances in technology, comes the introduction of dangerous chemicals that could pose risks to the environment. Indeed over 100 million chemical compounds are registered in the Chemical Abstract Service (CAS), a chemical registry system designed by the American Chemical Society, with new chemical substances being registered daily (Dulio et al. 2018). Chemicals used to benefit humanity can also generate environmental issues. While necessary for crop production, the use of pesticides can also negatively impact the environment and expose humans to mutagenic and neurotoxic effects. Similarly, plasticizers improve the properties of plastics (which is also considered a CEC), but human exposure to plasticizers results in carcinogenic and endocrine-disrupting effects (Pereira et al. 2015). Many CECs have endocrine-disrupting effects as well. They can imitate and impair the natural functions of the endocrine system in humans (Chang et al. 2009).

Contaminants of Emerging Concern	Pathways into the Environment	Adverse Effects
Pharmaceutica land personal care products	Industrial effluents and excreted metabolites	Endocrine disruption, antibiotic resistance, and other toxic effects in aquatic organisms (Abdel-Shafy and Mohammed-Mansour 2013)
Per- & polyfluoroalky l substances (PFAS)	Industrial effluents from manufacturing operations	Immune system dysfunction, carcinogenic and teratogenic effects (Boston et al. 2019)
Polybrominate d diphenyl ethers (PBDE)	Manufacturing operations, personal use, laundry, and disposal	Neurotoxic, endocrine-disrupting, and hepatotoxic effects (Pereira et al. 2015)
Microplastics	Fishing, tourism/recreation, indiscriminate waste disposal, laundry, and wastewater	Physical damage, inflammation, or exposure to toxic additives and other contaminants through their adsorptive property (Guzzetti et al. 2018)
Pesticides, herbicides, plasticizers and surfactants	Urban runoff, industrial activities, wastewater, and sewage treatment plants	Endocrine-disrupting, carcinogenic, mutagenic, teratogenic, and neurotoxic effects (Pereira et al. 2015)
Bisphenol A (BPA)	Industrial effluents from manufacturing operations	Endocrine-disrupting effects in humans and aquatic life (Javed et al. 2018)
Emerging Disinfection byproducts (DBPs)	Use of chlorinated disinfectant in water treatment	Carcinogenic effects (Westerhoff et al. 2016)

Table 1: Contaminants of emerging concern, their pathways, and adverse effects.

European Union research identified about 900 endocrine-disrupting compounds (EDCs) with the potential to cause major health problems, such as infertility, challenged infant mental development and changing sexual behavior in aquatic animals (Esteban et al. 2014; Plattard et al. 2021). Javed et al. (2018) reported endocrine-disrupting effects of BPA exposure in concentrations of 1-1000 μg/L in humans and marine life. While bioaccumulation of antibiotics through contaminated water ingestion can lead to antibiotic-resistant bacteria (Esteban et al. 2014), other CECs such as PAHs have been confirmed to have teratogenic, mutagenic, and carcinogenic effects (Huang et al. 2017).

While there are a few other mechanisms through which humans can be exposed to CECs, the focus of this analysis is on exposure through water pathways. The majority of CEC-laden industrial effluents end up in wastewater treatment plants (WWTPs), while others travel directly into surface water through runoffs (Li et al. 2015; Abdel-Shafy and Mansour 2016; Abdel-Shafy and Mohamed-Mansour 2013). The traditional WWTPs are primarily designed for the removal of dissolved and suspended organic matter, nutrients, and biological oxygen demand. WWTPs are often limited in their ability to remove emerging pollutants (Gilbride et al., 2021). This is a significant issue since the effluents of WWTPs are continuously discharged into surface water (Gilbride et al., 2021), therefore making PPCPs, flame retardants, PFAS, and several other CECs persistent in water streams. With growing research pointing to the adverse health effects of CECs, the lack of regulation and health guidelines for safe exposure limits continue to exacerbate the growing challenges surrounding these water contaminants (Brown and Cordner 2011). Conflicting information between industrial actors and public health officials adds to the uncertainty and anxiety surrounding CECs (Davies 2018). A major problem with this uncertainty is that it can be exploited by industrial players to lobby against regulations, prevent litigation, and sustain their profit margin (Auyero & Swistun 2008).

Efforts to prevent and remove CECs from Canadian drinking water, which is often sourced from surface water, compared to groundwater which is argued to be relatively protected (Abioye and Perera 2019), would yield tremendous gains in protecting and improving the health of millions of Canadians. The detection of emerging contaminants in groundwater (Stuart et al. 2011) further emphasizes the need for a quick response. In this policy analysis paper, a comprehensive and in-depth evaluation of key considerations and criteria for a good solution for the management of CECs is enunciated. This paper aims to provide an answer to a basic research question: what options exist for Canada to reduce and eliminate CECs? Considering the growing CECs challenges, this paper presents arguments around the need to address their prevalence in drinking water and presents some policy solutions, such as a science-policy approach in defining regulatory standards, as well as utilizing industry-led research toward finding efficient and cost-effective means to remove CECs from wastewater streams.

II. Challenges in addressing CECs in Canada

i. Existing water quality issues especially within indigenous communities

Home to about 20% of the world's freshwater resources (Freeman 2016; Lillo et al. 2021), Canadian communities are not excluded from the growing global water challenges. For decades, Indigenous communities in Canada have been challenged by various water quality issues. According to a report by Eggertson (2015), there were at least 1838 drinking water advisories in various on-reserve and off-reserve Indigenous communities in Canada. Consequent advice from the Council of Canadians to the government to address water pollution included analyzing the impact of economic activities on water sources and investing in wastewater/water infrastructure in Indigenous communities.

High levels of contamination in source water, and deficient water treatment facilities have led to a prevalence of drinking water advisories in Indigenous communities in Canada (Black and McBean 2018). Moreover, the drinking water advisory indicators are limited to microbiological parameters such as *Escherichia coli* (*E.coli)*, equipment and process-related issues, and some other non-health-related issues (Eggertson 2015; Environment and Climate Change Canada 2022). A regulatory gap exists here, as these indicators do not include CECs which are fast becoming a major global concern. To combat the problem of poor drinking water quality in Indigenous communities, Canada earmarked about $1.8 billion, in the 2016 budget, to be spent over five years, to improve on-reserve water/wastewater infrastructure (Indigenous and Northern Affairs Canada 2017). This effort has yielded considerable results. Environment and Climate Change Canada (2021) reported around a 45% reduction in the number of long-term drinking water advisories in reserve communities between November 2015 and September 2020. The numbers decreased from 105 in November 2015 to 58 in September 2020. Figure 1 shows the remaining long-term drinking water advisories, as of January 2024. However, to sufficiently achieve sustainable development goal 6 (SDG 6), which aims to ensure access to safe water, water infrastructure investments should not only be limited to addressing the current drinking water advisory indicators that only consider microbiological and aesthetic parameters but should also include the removal of CECs from drinking water and wastewater. As Current technologies are limited in the removal of emerging contaminants (Qu et al., 2013), it would be helpful if the government could consider the removal of recalcitrant, persistent, and emerging contaminants in the upgrade of water and wastewater infrastructure in future projects.

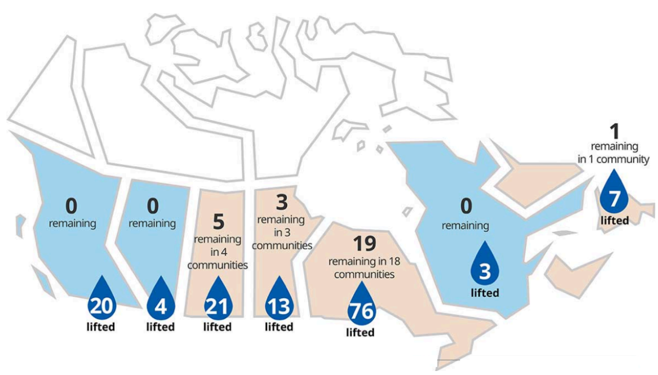

Figure 1: Remaining long-term drinking water advisories in 2024 (Ministry of Indigenous Services 2024).

ii. Slow regulatory progress

Furthermore, in Canada, the list of toxic substances (CEPA, 1999), which serves as an instrument to protect the environment and human health, is yet to include CECs such as pharmaceuticals, personal care products, and several others as priority substances. Even with growing evidence of the presence of various CECs in Canadian water bodies, regulatory response has been quite slow in addressing the situation (Naidu et al., 2016a). For instance, the analysis of water samples from the St. Lawrence River and its tributaries revealed the presence of CECs, including twenty-one different compounds detected in significant concentrations such as acetaminophen (500 ng/L), tetracycline (700 ng/L), triclosan (34 ng/L) and BPA (90 ng/L) (Berryman et al., 2014). Significant PFAS concentrations were also detected in Lake Ontario, Lake Erie, and Detroit River (Environment and Climate Change Canada 2009). Findings from Gilbride et al. revealed a dearth of data, resulting from a lack of research and data collection, on the amount of CECs discharged into the environment, making it difficult to quantify the magnitude of CECs in our environment, and to fully assess the harm to humans and the ecosystem. The lack of standardized analytical methods to detect and classify CECs in wastewater discharge was also noted; however, there are growing efforts in other jurisdictions to address them.

III. CECs management across the globe: Case studies on CECs regulations

i. North Carolina, United States of America

The prevalent use of PFAS contributes to drinking water contamination across the globe (Boston et al. 2019; Cordner et al. 2019). Studies regarding regulatory lapses in the management of PFAS in the drinking water of North Carolina provide a lesson for Canadian jurisdictions. The issue of industrial self-regulation and laid-back regulatory efforts are some of the noted challenges debilitating contaminants management. The United States has detected PFAS in drinking water at elevated levels in almost all 50 states (Wickham and Shriver 2021). PFAS, which has been in use since the mid-20th century, only started to receive attention from the US government and scientists in the early 21st century (Boston et al. 2019; Grandjean and Clapp 2015). Even with the emerging nature of PFAS, it was excluded from the US 1976 Toxic Substances and Control Act (TSCA; Richter et al. 2018). There is, however, an increased level of human exposure to PFAS through the use of modern water-resistant clothing, non-stick cookware, and grease-proof food packaging (Boston et al. 2019). Despite over 4,000 PFAS in existence, the US Environmental Protection Agency (EPA) later developed a health advisory of 70 parts per trillion (ppt) threshold for only two classes of PFAS (Boston et al. 2019; Cordner et al. 2019). Data from 2020, revealed PFAS contamination in over 1000 private wells in North Carolina (Sorg 2020). Researchers subsequently argued that the 70 ppt threshold was inappropriate for public health protection (Boston et al. 2019; Cordner et al. 2019). Cordner et al. noted that the PFAS guidelines made by the US EPA were influenced by aggressive lobbying from industry actors, where the 70 ppt threshold was guided by studies from PFAS producers (Cordner et al. 2019). The concerns raised here highlight the challenges involved in industrial self-regulation in the management of CECs.

Wickham and Shriver noted that North Carolina residents faced with industrial water pollution, specifically the PFAS GenX, filed litigation against the polluting company. A question that comes to mind is: are residents now left to take their future into their own hands regarding CECs? As much as this could be an indication of regulatory lapses, it is more concerning to note, from Wickham & Shriver (2021), that residents are beginning to lose faith in the regulatory agencies regarding CECs. The following quotes are some of the responses that emerged from Wickham & Shriver's studies. (1) '*the regulatory agencies have failed to properly alert the public about the serious dangers associated with GenX.*' (2) '*Nobody sent out flyers or anything. See, I've been there for so long that I know when there's a problem, they will send out flyers or the health department gets in touch with us.*' (Wickham and Shriver 2021). A resident further contacted the North Carolina Department of Environmental Quality (DEQ) to get his water tested for GenX contaminants; the response from the DEQ official is as follows: '*There's always something in the water…*' (Wickham and Shriver 2021). However, the US EPA has recently issued a legally enforceable standard for PFAS in drinking water. In the case of North Carolina, revelations from Wickham & Shriver (2021) showed a relative lack of political will toward addressing CECs, which the Canadian government should be wary of replicating.

ii. Minnesota, United States of America

Minnesota has taken a proactive lead in addressing the growing menace of emerging contaminants. In 2010, the Minnesota Department of Health (MDH) established a Drinking Water CEC program. The program is aimed at investigating and communicating the health and exposure potential of CECs in drinking water (Naidu et al. 2016a). The MDH Drinking Water program employed an interdisciplinary approach, combining science, policy, and advocacy as a tool for risk communication, assessment, and management (Prior et al. 2014). According to Brown (2013), this approach allows for effective input from the community, scientists, and regulators for managing public health risks. The MDH CEC program proactively considers existing and emerging contaminants in order to develop guidance for drinking water. This approach has assisted in managing CECs and identified areas of concern for future research (Wiener and Sandheinrich 2010). Furthermore, there are funds allocated by Minnesota law to address public health concerns related to this new class of contaminants (Naidu et al. 2016a). By committing $6 million over three years, Minnesota has appropriately addressed the need for sustained funding to address CECs. Similarly, as a preventive approach, the US EPA CEC program now screens new chemicals and manufacturing formulations for potential endocrine-disrupting effects (Naidu et al. 2016a). Naidu et al. (2016a) stated that both the MDH and US EPA CEC programs prioritize public participation in the process of assessing risks. The Canadian government can model Minnesota's ambitious approaches in providing a comprehensive solution toward solving the challenge.

iii. European Union's (EU) initiatives toward addressing CECs

Similar to Minnesota, the EU has also been proactive in contaminant management. In 2005, the EU funded an initiative – the NORMAN network (Dulio et al. 2018). This initiative, aimed at enhancing the exchange of information on emerging substances, has helped in monitoring CECs. As an independent forum for scientific deliberation regarding emerging contaminants, thus bridging the gap between science and policy, NORMAN (a non-profit organization) has played a major role in contaminant management (Dulio et al. 2018). To achieve its goals, NORMAN employs a multidisciplinary approach, bringing together the scientific community, private companies, and agencies involved in decision-making on emerging substances. This approach has been successful in disseminating knowledge about emerging contaminants and advancing scientific findings toward policy-making (Dulio et al. 2018).

Further, to monitor contaminants in the environment, the European Commission, through the Water Framework Directive, established priority substances, which are to be closely monitored (Solaun et al. 2021). The list of priority contaminants, which is updated biennially, was first established in 2008. For the first time in 2015, the list contained some CECs such as pharmaceuticals and synthetic hormones (Valbonesi et al. 2021). Subsequently, in 2015 and 2018, CECs were spotlighted for careful monitoring, with the goal of eventual regulation. This gave birth to a "Watch List". The Watch List includes contemporary CECs: PPCPs, hormones, antioxidants, and pesticides (Tornero and Hanke 2016). The EU list of priority contaminants did not only birth the new Watch List, but the constant updates have also encouraged the revision of the environmental quality standards (EQS), identification of new priority contaminants, defined EQS for existing and newly identified contaminants (Gorito et al. 2017). The European Commission has also mandated that the compounds identified in the Watch List must be monitored across all EU surface water (Barbosa et al. 2016). The EU largely utilizes preventative actions, as a tactic for addressing CECs, a demonstration of leadership (Gorito et al. 2017). The EU approach to contaminant management can be modeled to unify Canadian provinces and territories in their management of emerging contaminants.

iv. Australia's approach to managing CEC

Water Research Australia (2021) noted that CECs prioritization and the availability of credible data on CECs will assist regulators and water utility companies in responding to the growing issue. Efforts in toxicity research and the occurrence of CECs in water and other monitoring programs were further noted. However, limited regulatory guidance and a lack of suitable methods for analyzing them have prevented a unified approach to CECs management (Water Research Australia 2021). To address the regulatory gap, Australia has taken some proactive approaches including generating more scientific data, using the data to assess CECs risks, and ensuring effective communication between utility companies and the regulators. This initial approach led to the Emerging Chemicals Database for National Awareness (ECHIDNA) in Australia. ECHIDNA, a web-accessible data repository, was developed to facilitate risk assessment, enable information sharing among water professionals, and assist in the management of CECs. Using a multi-tiered approach, ECHIDNA has assisted in prioritizing CECs from an extensive list of contaminants in Australia. Tier 1 CECs are classified based on their persistence, bioaccumulation, and toxicity level. Endocrine-disrupting compounds (EDCs) and mutagens are therefore prioritized as Tier 1. As new information is available and incorporated, ECHIDNA continues to help consultants, academics, water utilities, and regulators make informed decisions regarding CECs management (Water Research Australia 2021). While the Canadian Environmental Protection Act (CEPA 1999) does provide a list of toxic substances, this list needs to be updated through evidence-based research, monitoring, and detection, to include numerous emerging contaminants.

IV. Global challenges, advances, and solutions in addressing CECs

Based on the previous insights, it is obvious that several factors have constrained the management of CECs, globally (Naidu et al. 2016b). European countries, Australia, and some jurisdictions in the US have started taking practical approaches toward addressing CECs (Boxall 2012). However, more is needed to be done regarding the synergistic/combined effects of different CECs in the environment, which is suspected to be more concerning than single contaminants. The suspected synergistic effects are yet to be fully understood (Boxall 2012). Also, the use of new chemicals in developing processes and consumer products makes the process of identifying and evaluating contaminants quite overwhelming. For instance, the EU first reported 66 EDCs, which has now been updated to about 900 (Naidu et al. 2016b). While several successes have been achieved through policies and regulations in other climes, it is still obvious that regulatory practices lag behind technological and industrial advancements (Naidu et al. 2016b). Considering these challenges, a more robust and comprehensive response toward managing CECs is inevitable. Researchers have noted the need for a more advanced and standardized method for quantification in complex matrices (Stuart et al. 2011). Highly sensitive and selective biosensors for detecting pharmaceuticals and EDCs have been proposed by Rodriguez-Mozaz et al. (2007) for improved CECs monitoring. Ultra Performance liquid chromatography (UPLC) capable of detecting up to 100 CECs at once in complex matrices has also been suggested (Gros et al. 2012; López-Serna et al. 2011). Other suggested strategies for CECs management are reducing their release into the environment (Stuart et al. 2011), and developing new remediation technologies (Das et al. 2013).

V. Major lessons from the jurisdictions considered

Lessons from North Carolina suggest that government inactions toward CECs could lead to a tipping point where residents lose faith in the regulatory authorities (and thus the government) in environmental protection. Other jurisdictions in Minnesota have somewhat lived up to expectations and have prioritized the need for CEC management. In these jurisdictions, public participation is encouraged allowing for effective responses from the community, scientists, and regulators. More so, the tightly knit political structure of the EU has encouraged more robust policies in the transboundary management of CECs. The exchange of information between scientific communities, regulators, and utility companies as seen in Australia and the EU would be a useful strategy in advancing scientific findings toward policymaking in Canada.

However, comparing the political structure and regulatory framework in these jurisdictions with Canada's would assist in assessing the feasibility of adopting the suggested strategies. Canada and Australia have a similar government structure, the federal system of governance, where the 10 provinces and three territories in Canada are comparable with the Australian states (Dunn et al. 2014). This similarity could aid in the adoption of working strategies in CECs' management from Australia. However, the EU's centralized governance results in uniform, legally binding water quality standards that ensure a higher level of consistency compared to Canada's decentralized system (Bereskie et al. 2017). Similar to the EU structure, the US also mandates legally binding, uniform drinking water quality standards by the US EPA Safe Drinking Water Act (SDWA; US EPA 2023). However, the SDWA also permits individual states to update their drinking water standards to set more stringent standards than the federal ones based on new scientific evidence (US EPA 2023). This has allowed the State of Minnesota to make ambitious steps toward CECs management. As the adoption of the Guidelines for Canadian Drinking Water Quality is voluntary and non-enforceable (Cook et al. 2013; Dunn et al. 2014), the borderless nature of water contaminants should trigger the need for a more collaborative effort among Canadian provinces and territories to attain a uniformly enforceable water quality standard while striving for more stringent regulations as new evidence emerges.

VI. Policy solutions

Taking a cue from the European Union, a feasible solution for regulating CECs would require a science-policy interdisciplinary approach to adequately understand the risk posed and to address the concerns through sustainable regulations and policies. Given Canada's slow action to address the risk of CEC, and the actions that other jurisdictions have taken, there are several options the government could take. A few policy recommendations, as well as their pros and cons, are herein suggested. The implications of each of the suggested policies are also analyzed.

i. Policy option 1: No action taken

Maintaining the status quo and taking no further action. Beyond the water challenges faced by the Indigenous communities, a lack of commitment to addressing CECs would continue to expose a larger proportion of Canadians to emerging drinking water challenges. Additionally, the potential health effects of CECs exposure will continue to pressure our health system.

ii. Policy option 2: Public engagement campaign

The need to communicate with the public to generate awareness regarding the prevalence and risk of CECs has become pertinent. Public participation and engagement such as town halls, awareness campaigns, and sensitization programs aimed at reducing pharmaceutical waste ending up in wastewater streams can be employed to engage the public. Incentivized expired-drug return programs could discourage improper disposal such as flushing medication down the drain. The US Drug Enforcement Administration's "take back" initiative provides an example that can be built on in Canada (US DEA 2024). The Health Products Stewardship Association (HPSA 2024) runs a free drug return program in Ontario, British Columbia, Prince Edward Island, and Manitoba. The HPSA program provides an avenue for the safe disposal of unwanted medications. However, the availability of such programs does not warrant their effective use by the public, hence, the need for public sensitization to educate the public on the need to protect our environment from CEC. While the success of this initiative may reduce household pharmaceutical waste, the reduction might be insignificant compared to pharmaceutical discharge from industrial waste. Furthermore, the scope of public engagement campaigns might be limited in addressing a broad spectrum of industrial emerging contaminants. Moreover, public engagement of this magnitude, using traditional channels such as town halls, could be cost-intensive averaging $200 per participant unless a more cost-effective online community engagement platform is used (Fillet Sören 2023).

iii. Policy option 3: Regulatory directives

Government policymakers and research institutions could partner to encourage a science-policy approach in defining regulatory standards for CECs. Similar to the ECHIDNA project, NORMAN network, and MDH CEC programs, such a partnership would aid the development of a comprehensive database, and exchange of information on CECs. It will also assist in investigating and communicating the health and exposure risks, as well as setting regulatory standards for their presence in drinking water. Moreover, industries should be mandated to give full disclosure of the chemicals they use, to provide comprehensive information that will aid regulatory standards. To ensure the sincerity of disclosure, regulatory oversight should be enforced. Periodic sampling of industrial wastewater effluents at the source by regulatory authorities could provide more information regarding the industrial chemicals used. Regulatory standards for CECs in wastewater streams and other contemporary contaminants should be defined with considerations of quantity, toxicity, and concentration. To facilitate this, reviews of current practices, and the development of workable regulations and guidelines to address CECs would be required through collaborative efforts between Health Canada and Environment and Climate Change Canada. The need for more collaborative effort among provinces and territories, through the Canadian Council of Ministers of the Environment, would ensure unified, legally binding, and enforceable regulations to better manage the emerging contaminants in the environment. Moreover, the scope of the transboundary water management relationship existing between Canada and the United States should be expanded to include CECs management and control.

iv. Policy option 4: Industry-led research to effectively pre-treat wastewater and reduce pollution load

Regulatory standards should be followed by an ultimatum to reduce pollution load in wastewater. This approach would spur industries to identify efficient and cost-effective means of treatment in order to remove CECs from wastewater streams and explore opportunities by which pollution loads could be reduced, including toxic raw material substitution, process modification, and the creation of industrial ecosystems through waste exchange arrangements. Industry-led research addressing CECs has been lacking due to the absence of regulatory standards for CECs. To further facilitate this approach, the Canadian government must urgently examine the costs and barriers of pre-treating wastewater. The government could provide relief in terms of research funding, through the Natural Sciences and Engineering Research Council of Canada (NSERC), to further encourage research in feasible treatment options, thereby reducing the potential cost implication on industries. This approach would provide technical and objective solutions to arrest CECs. Alternatively, the government could also consider providing tax credits for industries that invest in technology to pre-treat their waste to specified regulatory standards, with incremental fines for defaulters. Hospital waste discharge also falls into this category and should be adequately treated before being introduced into the environment. On average, it could cost around $12 million per day to pre-treat an average flow of a million gallons of wastewater (Johnson Matthew 2022). To lower the considerable cost, industries with similar pollution profiles could go into pre-treatment partnerships.

v. Policy option 5: Invest in academic research to generate new technology for CECs removal in drinking water

Effectively reducing the pollutant load in wastewater streams would limit the amount of CECs that end up in our surface water, thereby reducing the pressure on the water treatment plants. However, to adequately address CECs, the Canadian government should encourage research institution involvement and drive initiatives to create more awareness regarding CECs. As conventional water treatment plants are limited in their removal, nano-enabled water treatment technologies and advanced oxidation processes are some promising technologies. Therefore, the Canadian government needs to invest in upgrading existing treatment plants to incorporate newer technologies capable of removing CECs. In this regard, investment in environmental issues might be perceived as non-revenue generating and could slow down the required investment in advancing water treatment technology. However, a cost analysis would likely highlight the benefits of this investment. In the face of emerging health concerns related to CECs exposure, improved water quality would reduce money spent by the healthcare sector managing CECs-related health issues. A comprehensive risk assessment would justify the necessary financial trade-off to actualize the goal of improved water quality free of CECs.

VII. Policy considerations, and decision criteria

Given the policy options above, Table 2 gives a quick illustration of the environmental, health, or economic effects of considering each of the options, as well as the political feasibility ratings of the suggested policy options and the international reputation that could follow the adoption. As illustrated in Table 2, good solution criteria would be an option or a combination of options that would: (1) reduce the prevalence of CECs in our environment, and protect the public health and livelihood, (2) provide considerable investment which would be offset by the overall benefit of long-term environmental and socioeconomic sustainability, (3) be widely accepted by the public, both locally and internationally. Beyond achieving SDG 6 (Access to safe water, sanitation, and hygiene), the solution criteria described here would aid in achieving other SDGs such as SDG 3 (ensuring healthy lives and well-being for all, at all ages), SDG 14 (protecting and sustaining aquatic lives) and SDG 8 (ensuring improved productivity through healthy workforce). A good solution to CECs would also reduce the strain on our health sector.

i. Implications of each policy option

Every policy is as good as their political feasibility, and the reputation it would bring among a comity of nations (international reputation). The political feasibility of each suggested option is rated either adequate or good based on the relative ease and convenience of extracting the needed political will among policymakers to adopt the suggested option. The international reputation is considered either problematic or good based on its perceived acceptability within the international community. A policy is considered problematic in ensuring environmental protection if its outcome would yield no environmental, health, and economic benefits. Policy option 1 is argued to have fallen into this category. Maintaining the status quo (Option 1) would allow CECs to continue to impact our environment, health, economy, and reputation (EHER) negatively. Maintaining the status quo is thus analyzed (Table 2) as being problematic given the EHER criteria. However, a lack of adequate knowledge about the risks posed by CECs could falsely justify Option 1. A policy option is described as adequate if the outcomes would ensure environmental, economic, and health benefits. Policy option 2 falls within this category. A public engagement campaign (Option 2), to some extent, would reduce CECs in water and wastewater streams. With minimal financial commitment, this option is rated adequate for reducing environmental impact and improving health & well-being. With some challenges regarding public adherence, the option is also quite politically feasible and deemed adequate. Options 3, 4, and 5 are considered to be good policy options as they are perceived to offer good environmental, economic, and health returns with some level of political feasibility, albeit with considerable financial commitment. While the implementation of option 3 might not be constrained by the national budget, options 4 and 5 would require considerable budgetary allocations. Therefore, a strong political will is required to implement these three options. The implementations would comprehensively satisfy the EHER criteria, translating into an improved environment, health and well-being, and good international reputation.

VIII. Conclusion

The absence of regulatory standards for the majority of the CECs, and the non-revenue generating nature of water and wastewater treatment investment have led to limited effective efforts toward addressing CECs challenges. However, collaborations and investment to sustain health and well-being would result in a healthy workforce and improved productivity for the nation (SDG 8). Based on the policy considerations and decision criteria defined in this paper, options 3, 4, and 5, adopted one after the other, seem most feasible for addressing CECs comprehensively. Government funding and industry-led efforts would hasten research-oriented solutions to effectively set regulatory standards for CECs in drinking water and to remove CECs from drinking water and wastewater streams. To start with, initiatives from research and development would largely guide the development of adaptive and comprehensive environmental regulation strategies for CECs. Notably, as recommended in policy option 3, regulations should go beyond defining maximum concentration limits in waste discharges. It should also define a range for the quantity of waste to be discharged. Water and wastewater regulation guidelines should preferably define the pollutant load (concentration x quantity discharged) rather than concentration alone. With a plethora of ongoing water-related lab-scale research, the implementation of the recommended policy option 3 would consolidate the implementation of policy option 4 and prepare the ground for the systemic implementation of policy option 5 which would ultimately translate into improved environment, health & well-being, and good international reputation.

Criteria	Environmental Impact (SDGs 6 & 14)	Health & Well-being (SDG 3)	Economic Impact (SDG 8)	Political Feasibility	International Reputation	Overall
Policy Option 1	X	X	X	Δ	X	**X**
Policy Option 2	Δ	Δ	Δ	Δ	○	**Δ**
Policy Option 3	○	Δ	Δ	○	○	○
Policy Option 4	○	○	Δ	Δ	○	○
Policy Option 5	○	○	Δ	Δ	○	○

Key

Symbol	○	Δ	X
Description	Good	Adequate	Problematic

Table 2: Criteria illustrating the benefits and feasibility of the suggested policy options.

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