Bioavailability and Significance of Endocrine Disruptive Compounds in Ecosystems

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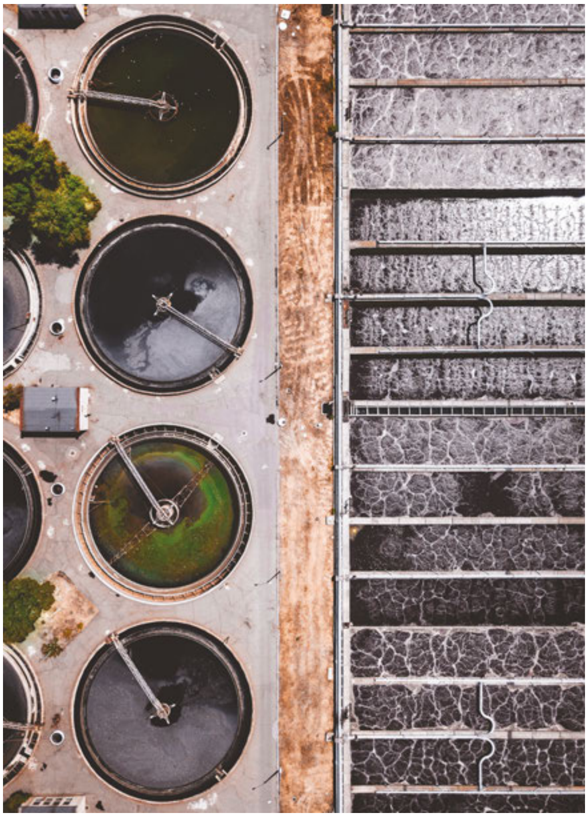
Conventional treatment plants of domestic wastewater (WWTP) are one of the key point sources for micro-pollutants including low levels residues of Endocrine Disruptive Compounds (EDCs) and their derivatives that are detected in the discharged secondary and tertiary effluent. The EDCs residues that reach the recipient environment and the ecosystems can be subjected to uptake and bioaccumulation in soil and groundwater in aquatic and terrestrial organisms, and/or human body.

To avoid risk, further treatment in a form of activated carbon adsorption and ozone-based advanced oxidation process (AOP) prior to chemical or UV disinfection are being considered before disposal of the effluent to water bodies or recharged to aquifers. Such techniques are extensively tested and even used on a commercial scale, adding the "fourth treatment step." While the technical and the cost of the additional treatment are apparent, the threat to the ecosystems and public health which may derive from the minute quantities of the EDCs residues that escape tertiary treatment is not evident to justify the additional cost which may restrain water reuse, a vital source of water for irrigation and food security in arid and semi-arid regions, boosted by UN SDGs, 2030, which endorse water reuse and circular economy.

To assess and evaluate the various aspects of the EDCs residues and their impact on the ecosystems, an IUPAC project lead under the Chemistry and the Environment Division was constituted to review the current literature (2015-2022), as well as the experience gained by leading countries which promote the fourth treatment step of effluent, focusing on:

- Tertiary effluent and reclaimed water reuse and associated monitoring and regulation.
- Health and ecosystems impact of EDCs residues and derivatives, sourced to tertiary domestic effluent.
- Costs barriers to universal water reuse.

The preliminary findings and conclusions of the review are briefly summarized in the present *interim* report, pending the completion of the final report, in progress.



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Resistance to Biological Degradation and Potential Health Impact

Residues of pharmaceutical and similar compounds, being recalcitrant to biological degradation may go through the wastewater treatment process almost unchanged, ranging from 7 to 23%, for substances such as Carbamazepine (CBZ) and Diclofenac. Tertiary effluent recharged to groundwater aquifers forming a barrier against seawater intrusion and or pumped back as reclaimed water for use for irrigation or direct potable reuse (DPR), after further treatment, were found to contain EDCs residues and derivative that are detected in the recipient environment in soil and groundwater (Paz *et al.,* 2016), in aquatic and terrestrial organisms, and human body. Their likely uptake by the food crops poses potential hazard for food safety and human health risks (Ribeiro *et al.,* 2016).

However, the fate of the EDCs residues in the recipient soil is regulated by adsorption and leachate, biodegradation, photodegradation and hydrolysis processes, which alleviate their bioaccumulation in soil, groundwater and uptake by plants and the food chain based on the chemical-physical properties of the residues, the molecule's charge and soil characteristics (Avisar and Ronen-Eliraz, 2017).

To date, uptake and accumulation of such residues, typically within the ng/ gr range, in edible crops, as potential route for human exposure *via* dietary ingestion was reported to be insignificant to pose a health risk (Compagni *et al.,* 2019). In addition, possible additive "cocktail" effects from the combined presence of many EDCs and other chemicals in the environment and the underlying mechanisms of the minute residues of EDCs on the ecosystems, the wildlife, and humans are still not fully understood, as well as and their toxicological impact on larger organisms. Furthermore, their occurrence in minute quantities can be an analytical challenge. This state of affairs attracted the initiation of the EU funded program, combining eight research projects, assigned to carry out a comprehensive study of the EDCs, being an innovation program and the largest public funding of this type of research in Europe (EURION, 2020).

Tracing of EDCs Residues

The Endocrine Disruptive Compounds show similarities with hormones and enzymes compounds regulating metabolic functions of living organisms. But, the variety of the EDCs substances constitutes one of the main challenges to assess and control their residues in the environment. Tracing EDCs residues in the environment and the ecosystems is carried out using indicator pharmaceutical compounds such as the CBZ (Hai *et al.,* 2018). A survey of CBZ contents, in raw wastewater and in effluent before and after groundwater recharge, now in its fifth year, shows very little change and the concentration remain at the range of 500 ng/ L^{-1}, while the level of CBZ at the adjacent natural water is very low (0.011 ng/ L^{-1}) (Aharoni *et al.,* 2019).

Water Reuse and Regulation

Effluent after tertiary treatment is widely used for crops irrigation, especially in water scarce regions where water reuse is the major alternative for edible food production essential for human consumption. Israel leads the world in reuse of the generated wastewater (85%), recycling about 500 million cubic meters annually, substituting 40% of potable water used for irrigation, nationwide. Other water scarce countries are following suit (Shevah, 2019).

In the absence of clear evidence, indicating irreversible ecological and functional damages to health, the occurrence of EDCs in the reclaimed water used for irrigation is not regulated by law. The current legal implications in the European Union do not clearly enforce the control of the micro-pollutants in the aquatic environment and unrestricted irrigation with tertiary treated effluent is allowed, enabling agricultural production and food supply for the population in arid zones and drought prone regions. However, the need to address the impacts of EDCs on human health and the environment is highly relevant to the public and the issue of pharmaceutical residues cannot be ignored, in line with the EU directives on EDCs linked to water reuse and endocrine disruptors (Mara-Ceridono, 2020) and the inclusion of two EDCs (beta-estradiol and nonylphenol) in the watch list of emerging compounds in drinking water.

EDCs Residues Removal Technology

Increasing micro-pollutant residues in the European surface water have urged leading countries including Switzerland, Germany, Netherlands and others to initiate work, targeting the removal of pharmaceuticals and personal care products (PPCPs), EDCs and other contaminants of emerging concern from urban wastewater. The advanced treatment step referred to as the "fourth treatment step" comprises of membrane ultrafiltration (UF), bio-filter using powdered activated carbon (PAC) and granulated active carbon (GAC) and catalysts like ozone and titanium in combination with UV-light. As found necessary, sand filtration is used to remove any toxic biodegradable transformation products formed during ozonation and small PAC particles (Prasanna *et al,* 2020). Other techniques include advanced nanofiltration (NF), hollow fiber direct NF and reverse osmosis (RO) membranes designed to achieve higher removal rates (above 99%) for targeted compounds. RO is used in the USA, especially for treating effluent intended for direct potable reuse.

Costs of the Fourth Treatment Step

A comparative study of costs for three different techniques (powdered activated carbon dosing to activated sludge systems (PACAS), ozone combined with a sand filter and GAC filtration) and three scales of treatment plants revealed that the removal of EDCs residues would amount from € 0.22 to € 0.29/m^3 for small treatment plants and € 0.16 to € 0.26/m^3 for large scale plants (STOWA, 2019). In terms of water reuse, prices for indirect potable standard water are in the range of €0.26 to €0.35/m^3.

Global Experience in EDCs Regulation, Monitoring and Residues Removal

The experience gained in treatment and removal of EDCs in leading countries, in Europe, USA, Australia, Singapore and Israel focus on advanced treatment technologies, with emphasis on micro-pollutants removal and the likely impact on wastewater reclamation and reuse, considering OECD Policy which advises governments to opt for a life-cycle management of PPCPs production, prescription and use, prevention and healthy life-style rather than cure and treatment to prevent pharmaceuticals from ending up in water bodies. To contribute to the economic sustainability of the healthcare sector, employing a Green Deal to convince doctors to reduce unnecessary use of pharmaceuticals, re-engineering the products and making them more environmentally friendly.

Preliminary Conclusions

Wastewater reuse is a valid and a vital policy to increase the availability of water resources, preventing a severe pollution of various aquatic environments by discharge of wastewater and more important to alleviate droughts and water scarcity in drought prone regions. Nowadays, over 2 billion people live in countries with high water stress and lack of sanitation, and about 4 billion people experience severe water scarcity due to local pollution and droughts. The situation may get worse due the impact of the climate change.

However, despite the widely accepted assumption that the environmental and public health impact of minute EDCs residues are inconclusive (Compagni *et al.,* 2019), not waiting for conclusive results, leading countries who have the technical and the financial means, have introduced, or are considering, the Fourth Treatment Step designed for effective removal of EDCs and minimization of micropollutants residues in effluent (STOWA, 2019).

Such excessive and expensive treatment, not affordable by all, is fast developing, creating a barrier to the global water reuse, especially in the developing world, unable financially to embark on large scale water reuse, despite the vital need for recycled water for food production and food security. To avoid a setback in water reuse, a minimum standard for reclaimed water quality and compliance monitoring are recommended so that farmers can safely use reclaimed water for crop production, learning from the experience gained in countries, which have been successfully reusing water for decades. In parallel, in-depth risk analysis, and research filling the knowledge gaps as initiated by EU shall be intensified, to ensure that any EDCs residues are not causing irreversible ecological and functional damages to health.

The reported preliminary review of the current knowledge and impact of EDCs residues reaching consensual recommendations by the wide group of experts comprising the Working Group including missing research will be further elaborated and presented in a forthcoming Report.

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See IUPAC project https://iupac.org/project/2018-013-2-600/

IUPAC Projects Contributions to the UN Sustainable Development Goals: Past, present, and future

by Pietro Tundo and Jane Wissinger

Development of truly Green and Sustainable Chemistry is key to delivering many of the United Nations Sustainable Development Goals (UN SDGs) [1]. To effectively address the huge challenges faced globally, scientists must understand the wider context of Sustainable Development.

On 8 July 2019, the Interdivisional Committee on Green Chemistry for Sustainable Development (ICGCSD) organized a special symposium, "Chemistry Addressing the UN-17 Sustainable Development Goals," at the IUPAC World Congress in Paris. The purpose of the Symposium was to link together research and industry with exchange of ideas on this significant issue of the future.

This half-day symposium included invited lectures and expert panel discussion and was organized by Pietro Tundo (Chair IUPAC ICGCSD), Christopher Brett (IUPAC President Elect), Janet L. Scott (Secretary of the ICGCSD), and Fabio Aricò (IUPAC Division VIII -Chemical Nomenclature and Structure Representation- Representative). Invited speakers, including Michael Greatzel, Kris Matyjaszewski, Haoran Li, Natalia Tarasova, Klaus Kümmerer, and Mary Kirchhoff, provided perspectives on science, policy, regulatory, societal and business strategies that could enable more rapid movement towards realizing the "shared blueprint for peace and prosperity for people and the planet, now and into the future" [2] that the SDGs are designed to realize. The role and the connection of IUPAC with international organizations was emphasized. In all cases, topics included aspects of science policy or green and sustainable chemical research that support these strategies.

With this symposium, attended by about 200 persons, ICGCSD's intentions were to open a dialogue on Green Chemistry and Sustainability with relevant international industries and chemical organizations. Initial collaborations involved chemical industries that were willing to develop the best practices in appropriate manufacturing fields (chemicals, processes, products, etc.).

Project Aim

For over a century, IUPAC has been a world leader in global issues involving the chemical sciences and their societal impact. Nowadays, this work is primarily conducted through a project-driven system where proposals are peer-reviewed from within the Union and its 13 divisions and committees, as well as from the broader academic and industrial chemistry enterprise. In 2000, IUPAC's mission was revised to "assist the chemistry community in collaborating with scientists in other fields, engineers, technologists, and policy makers to solve critical world problems." [3] These strategic initiatives were thus incorporated into many of the IUPAC projects conducted in the last 22 years with a focus on the application of the chemical sciences for the "betterment of humankind"; in other words, a sustainable future.

There is arguably no more prominent roadmap for a sustainable future than that defined in 2015 by the United Nations Sustainable Development Goals [1]. To illustrate IUPACs leadership in achieving the SDGs, even before their publication, Pietro Tundo initiated a project (2020-011-2-041) with the aim of assessing the contributions of IUPAC projects to the achievement of the 17 SDGs [4]. This article describes progress to date on this project and potential opportunities for dissemination.

Towards that end, IUPAC projects were reviewed between 2000-2021 and 262 were selected across all divisions and committees for critique on their relevancy to the 2030 goals. A master spreadsheet was prepared by Aurelia Visa (ICGCSD) and a representative from each division and committee was tasked with identifying a primary SDG for each project. However, it quickly became evident that most projects included multiple targeted outcomes with many having a *Quality Education* (SDG 4) and/or *Partnership for the Goals* (SDG 17) component. Therefore, both primary and secondary UN SDG targets were assessed. Further refinement to consider alignment with the 169 UN SDG Targets provided the most accurate representation of project goals. (For references to the 17 SDGs and specific Targets, see ref [1])

Preliminary Results

Committee representatives' reviews of the initial 262 projects identified 253 projects as having a primary relationship to one of 12 of the 17 SDGs. As illustrated in Figure 1, 78% of the primary goals were classified within four major SDGs areas with further association