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Emerging pollutants (EPs) in Latin América: A Critical Review of under-studied EPs, case of study -Nonylphenol-

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Abstract

Emerging contaminants (EPs) represent a significant risk to human, ecological and environmental health. Although progress has been made in establishing monitoring in environmental matrices, health effects, legislation and control, there are still problems associated with regional bias and the types of EPs commonly assessed, which may underestimate the risk to health. In Latin America there are limited reports on environmental monitoring of EPs and it is generally focused on wastewater. This review identifies the current research deficiencies for emerging contaminants in the Latin American region, and we address the case of nonylphenol as an understudied EP in the region. Nonylphenol is a degradation product of nonylphenol ethoxylate, which is a surfactant widely used in the manufacture of detergents in Latin America, environmental concentrations have been reported, predominantly in water, and the possible effects on species in this region have been also described. The importance of the review of this compound in the region lies in the fact that the Rotterdam Convention has catalogued nonylphenol as a severely restricted compound, so it is necessary to establish measures for its restriction and change to a sustainable technology.

Finally, the example of NP presented in this review highlights the lack of regulation in Latin America regarding to EPs, resulting in the contamination of wastewater, effluents, rivers and drinking water. It is imperative to determine the potential effects, occurrence and concentration levels to improve the regulation of these pollutants in a timely manner.

Keywords: Emerging pollutants; Latin America; nonylphenol, human risk; ecological risk

1. Introduction

In the last two centuries, the use of chemicals has contributed to the economic and social development worldwide. As a result, thousands of chemical mixtures (synthetic and natural) are now present in the environment and daily life. Global production of synthetic chemicals has increased exponentially, between 1903 and 2000 the annual chemical production increased from 1 million to 400 million tons and from 2002 to 2011 more than 50% of chemicals were classified as environmentally harmful and 70% with significant environmental impact. By 2017, 97.8 million tons were reported as hazardous to the environment and 91.8 million tons as hazardous to health (EUROSTAT, 2019; Gavrilescu et al., 2015; WWF, 2020). There are more than 80,000 chemicals that are used in manufacturing products to meet human needs such as, cleaning products, drugs (prescription and over the counter), cosmetics, fragrances, personal care products, among others. These products are used and disposed of globally in the environment after a manufacturing process as industrial waste directly impacting on water quality (Naidu et al., 2016).

In general, water quality research focuses on nutrients, microbial contaminants, heavy metals and priority pollutants. Recently, there has been acknowledged a new type of pollutants (“emerging pollutants”) that affect significantly the quality of water and causes potential public health and security problems (Bilal et al., 2019). However, due to its recent detection and low concentrations (µg L^{-1}, ng L^{-1}), there is a gap in knowledge about its occurrence, fate, behavior, risk assessment, and ecological and human effects. These compounds includes daily use products like surfactants, flame retardants, pharmaceuticals, personal care products, biocides, gasoline additives, polar pesticides and their degradation products. The main source of EPs are municipal wastewaters (Deblonde et al., 2011) and conventional water treatment plants that are not designed to remove this kind of pollutants and their degradation resistant metabolites, so they are disposed of directly into water bodies (Van Zijl et al., 2017). The investigation of the composition of EPs and their removal during wastewater treatment is scarce, due to the lack of monitoring programs because of the non-existing specific regulations (Rasheed et al., 2019). The occurrence of EPs in wastewater, its behavior during treatment and the production of drinking water are then key areas that require immediate studies.

2. Emerging pollutants and its importance in human and environmental health

EPs emissions have become an environmental global problem because of the limited regulations and worldwide consensus that establish legislations in this regard. The Environmental Protection Agency (EPA) defines the EPs as chemical compounds without regulations where its behavior, environmental and public health impacts are poorly understood (EPA, 2017). Some of these compounds present endocrine disruption activity and they have been defined as exogenic agents that interfere with the synthesis, secretion, transport, binding or elimination of natural hormones in the human body that are responsible for the homeostasis, reproduction, development, and behavior (EPA, 2017). Therefore, the presence of these pollutants may affect the development of embryos, sexual differentiation, and metabolism (Flint et al., 2012). Some of the effects that have been described are: altering the reproductive system, the sexually-dimorphic neuroendocrine system, affecting endogen levels of steroids, diabetes, cardiovascular problems, abnormal neuronal behavior and they are obesity-related (Arlos et al., 2018; Silva et al., 2018; Vilela et al., 2018). These xenobiotics are found in most products manufactured for personal use like plastic bottles, children toys, cosmetics, toothpaste, detergents, drugs (hormones, anti-inflammatory, anti-epileptic, statins, antidepressants, beta-blockers, antibiotics, contrast products, etc.), among others (Gavrilescu et al., 2015). There are mainly utilized in domestic, veterinary and in hospitals (Deblonde et al., 2011). The use of these chemicals has increased occurrence in wastewater, groundwater, surface water and drinking water in urban areas being the main pollution source wastewater from laboratories, hospitals and medical facilities (Gavrilescu et al., 2015). Nevertheless, there are other pollution sources as human and animal defecation (partially or completely metabolized), disposal of products without previous use (Gogoi et al., 2018; Poynton and Vulpe, 2009), domestic sewage, septic tanks, industrial effluents, urban wastewater, agricultural practices, showering, household cleaning, and recreational activities (Daghrir and Drogui, 2013). Although some of these chemicals are hydrophilic, water-soluble and with a short life period (Fent, 2008), others can be persistent in the environment without degrading for years (Tijani et al., 2016). Even though concentrations in the environment are at trace levels (Pal et al., 2012), these may generated adverse effects in water quality and represent an estrogenic risk for ecosystems and human health (Sirés and Brillas, 2012).

3. Regulatory frameworks for emerging contaminants and the problem of implementation

Outstanding in continuous monitoring measures and regulation of maximum permissible limits in environmental matrices are the United States and the European Union through their environmental regulatory agencies (**Table 1**). For example, the EPA created the Drinking Water Contaminant Candidate List which includes some drugs like carbamazepine, naproxen, sulfamethoxazole, ibuprofen, gemfibrozil, atenolol, diclofenac, erythromycin, and bezafibrate (EPA, 2018).

For the EU, it introduced a list of priority pollutants under the European Union Strategy for Endocrine Disrupters that includes 564 chemicals believed to have some form of disruptive activity (Stefanakis and J.A, 2015). Moreover, it constituted the EU Collaborative Project SOLUTIONS (Brack et al., 2015) and the European Monitoring Network NORMAN (www.norman-network.net) evaluating over 1036 EP. The mission of these investigation efforts is to improve evidence to make policies for identification, assessment, and prioritization of this compounds (von der Ohe et al., 2011).

Attempts to improve water and environment quality have resulted in the creation of regulation trying to reduce hazardous chemical use and production. However, even when significant advances have been accomplished, chemical pollution is still a substantial risk in at least half of the water bodies recently monitored in Europe (Malaj et al., 2014). The EU reports more than 100,000 chemicals and between 30,000 to 70,000 are used in daily life (Loos et al., 2009). It is expected that an important, but unknown, fraction of these chemicals finds its way into the environment and water systems with a considerable number of transformation products and byproducts that may create complex mixtures (Brack et al., 2015). There are regulatory frameworks to monitor and manage potential pollution sources of some priority pollutants in the aquatic environment, but EPs are not subject to the same regulations. There are no specific regulations for new compounds, byproducts, drugs, and personal care products so there are few or none precautions to assure the no disposal to the drainage (Bolong et al., 2009). Thus, wastewater is considered the main pollution source in the environment and surface water (Lapworth et al., 2012) as maximum concentration levels for disposal have not been established (Gogoi et al., 2018). The management and usage of these chemicals are challenging for the government because of the little information about impacts, fate and concentration levels of EPs in the environment; hence there are few global agreements on which EPs need to be observed (Rodriguez-Narvaez et al., 2017).

There is a current and continuous urge to create and enforce new directives shortly because of the increasing and undefined risks that the exposure to EPs represent (Stefanakis and J.A, 2015). A monitoring strategy of EPs in water is essential to protect and improve water quality. The spaced and temporary variability of many EPs in the environment is a topic of growing interest from a regulatory and research perspective, so an increase of regulated compounds is expected soon.

4. Emerging pollutants in Latin America

Research on EPs in Latin America is recent even though their concentration levels have increased significantly in the past 10 years (Bedoya-Rios et al., 2018; Botero-Coy et al., 2018; Hernandez et al., 2015). In 1999, one of the first studies was published in this regard, where they reported to found drugs and its metabolites in water bodies from Rio de Janeiro and discussed the lack of information of EPs in Latin America (Stumpf et al., 1999).

The studies aimed at monitoring in different water matrices, have been conducted with analytical methods, the reported limits of detection and quantification are similar to those employed by other countries, however they are focused on research so it cannot be sustainable for long-range monitoring. It is important to note that the concentrations and number of compounds are 4 to 5 times higher than those countries that have legislation (**Table 1 supplementary material**).

The main problem according to the United Nations Environment Programm is that the acknowledgment about the prevalence of EP is limited (UNEP, 2017). Furthermore, there are two important issues in these studies, i) there is a regional bias and ii) the EPs commonly evaluated, these factors may lead to sub-estimation of health risks associated with these compounds. Regarding the first issue, a review conducted in 2016, indicates that from the 631 studies reported, 221 were from Germany, 143 from the United States, 83 from Spain and only 23 studies from Africa (aus der Beek et al., 2016). Particularly in Latin America and the Caribbean, a smaller number of studies have been reported to the date, a previous review indicated that from 1999 to 2018 there are 57 studies of EP in wastewater (Peña-Guzmán et al., 2019), another review presented only 23 investigations of EP in marine biota and freshwater from 2002 to 2016 (Llorca et al., 2017). Regarding to the second issue, the most reported pollutants in this region are: antibiotics, antacids, steroids, antidepressants, analgesics, anti-inflammatories, antipyretics, beta-blockers, lipid-lowering drugs, tranquilizers, stimulants, drugs (prescription and over the counter), phthalates, phenolic compounds (bisphenol A, nitrophenol, alkylphenols, and chlorophenols), triclosan, ethinylestradiol, diethylstilbestrol, 17-β estradiol (**Supplementary material, Table 1**)(Barrios-Estrada et al., 2018; Gogoi et al., 2018; Rivera-Utrilla et al., 2013; Stuart et al., 2012; Yan et al., 2014).

Latin American countries with less protected areas present a larger population and major biodiversity loss. However, to the date, there is no estimation of the relative impact of the pollution in biodiversity (Rodriguez-Jorquera et al., 2016). The aquatic environment may be the most threatened habitat because the wetlands sustain biodiversity and provide essential ecosystem services (Zedler and Kercher, 2005).

The lack of regulations in Latin America allows an accelerated and increased discharge of EPs representing an important risk in environmental and public health impacts (Qiu et al., 2016; Silva et al., 2018). Moreover, like in other geographic regions, there is little information to be able to establish EPs trend and are focused on the commonly assessed compounds. The objective of this review is to show the example of an EP widely used which presents scarce information in Latin America about its disposal and the great implications that may cause in human and environmental health, the nonylphenol.

5. Case study of emerging pollutants under-studied in Latin America. Nonylphenol

Nonylphenol ethoxylated (NPE) is a non-ionic surfactant usually employed as a surfactant in domestic and industrial detergent formulations (Quiroga et al., 2019; Vazquez-Duhalt et al., 2005). The use of NPE in detergents represents 80% of its demand because of the low cost and the great detergent capacity (Araujo et al., 2018). Another uses include herbicides, pesticides and in production of paper, textiles, plastics, rubbers and paints (Ferrara et al., 2011; Perron and Juneau, 2011). The high industrial demand and its use in anthropogenic activities have increased its occurrence as a pollutant in sewage sludges and landfills mainly because of waste discharges, water treatment plants and accidental spills (Qiu et al., 2016; Silva et al., 2018). In environmental conditions, NPE is degraded by microorganisms or ultraviolet light transforming them into nonylphenol (NP) including mainly the 4-nonylphenol (4-NP) (**Figure 1**) (Cheng et al., 2017). It has been reported that this metabolite is more resistant to degradation, possesses endocrine disruptive activity and is highly toxic to aquatic and terrestrial organisms because of its ability to mimic the feminine hormone 17β-estradiol (Forte et al., 2016). Removal percentages of NP in water treatment plants vary from 9 to 94% depending on the process used. For example, a previous study showed only 9% of biodegradability after 56 days in water and 4.2% after 28 days in sediments (Vazquez-Duhalt et al., 2005). The removal efficiency is affected due to the fact that the conventional treatment plants are not designed to process this kind of pollutants (Ruhí et al., 2016) and also due to the chemical structure stability of these compounds (Gavrilescu et al 2014). Efficient degradation of EPs may require coupled systems to compensate for the shortcomings of using a single technology for the removal of these complex compounds in water (Rodriguez-Narvaez et al 2017), novel techniques, such as lacquer-assisted degradation of EPs, have gained particular interest because of their uniqueness and applicability (Barrios-Estrada et al 2018). The development of new technologies for the treatment of EPs in waste water treatment plants is therefore essential for environmental monitoring and in support of policies to control EPs concentrations in wastewater. In addition, the NP can be transferred between water and air because of its semi-volatile property so it can be transported to aquatic and terrestrial ecosystems by wet deposition (rain or snow) (Chen et al., 2013). Even though the concentration of NP can decrease because of the effect of the sun over surface water, there is evidence that NP in sediments has an average life span of over 60 years which represents a constant exposure to all organisms (Soares et al., 2008).

4.1. Effects on ecological health by NP exposure and implications in Latin America

The main disruptive endocrine activity of the NP is the ability to mimic the feminine hormone 17 β-estradiol. However, this is not the only mechanism that the NP uses to disturb the endocrine functions of organisms. Other examples include change of sex, raise of hermaphroditism, decrease of testosterone elimination, fecundity reduction, mutations, deformities, increase in mortality, gonadal development inhibition, low testicular mass, ovaries development inhibition and fertility reduction (Buñay et al., 2017; Forte et al., 2016; Patino-Garcia et al., 2018; Uguz et al., 2015).

Some studies have evidenced that exposure to NP may cause undesired morphological, physiological and structural effects in different types of plants (de Bruin et al., 2019). The exposure of 1000 mg Kg^{-1} of NP caused cell necrosis in leaf veins in mung bean (*Vigna radiata*), a commonly grown legume in Latin America (Kim et al., 2019).

Previous studies in fish have demonstrated adverse effects by NP exposure, for example, it has been shown a gonadosomatic index decrease in a red seabream and black rockfish associated to the exposure of 50 µg L^{-1} of 4-NP (Saravanan et al., 2019); Japanese quails exposed to 4-NP presented a decrease in male spermatogenesis and pathologic damage in male gonads (Cheng et al., 2017); the immune system of rainbow trouts (*Oncorhynchus mykiss*) was affected after NP exposure with concentrations considered as safe for aquatic species (1 µg L^{-1}) (Hébert et al., 2009); a kind of fish with hermaphrodite tendency (*Acanthopagarus latus*) and the more marketed for its consumption in Iran exposed to 4-NP showed alterations in steroids and thyroidal levels (Naderi et al., 2014). The exposure of NP in concentrations of 16 µg L^{-1} in *Oreochromis niloticus*, a widely distributed species in Latin America, has shown significant alterations in female gonads (Rivero et al., 2008). Effects in Cladoceran *Daphnia magna* have been previously reported, exposure µg L-1 of 4-NP reduced the metabolic elimination of testosterone in 50% and in concentrations of 100 µg L-1 the fecundity (Baldwin et al., 1997). Another study in *Moina macrocopa* demonstrated that the exposure to 15.4 µg L^{-1} of NP resulted in decreased fecundity (Hu et al., 2014).

In vivo experiments have shown that in murine models, the oral exposure of 4-NP causes a significant reduction in the capability of forming colonies and duplicating mother mesenquimals mother cells population which prevents bone regeneration and originates potential risks of acquiring bone diseases like osteoporosis (Abnosi and Shojafar 2014).

On the other hand, some species may absorb higher concentrations of NP through skin so direct contact must be considered as an important exposure pathway. In *Salmo salar*, NP exposure increased the hepatic estrogenic receptors detected in skin (Arukwe and Røe, 2008), pathological alterations in skin of amphibians that can easily interfere in physiological functions have been reported (Brunelli, 2018) and there are available reports stating that the exposure to low concentrations of NP may increase cases of atopic dermatitis in mammals (Sadakane et al., 2014). Freshwater zooplankton organisms have reported that toxones like *Acroperus* and *Calanoida* are highly sensitive to 76 µg L^{-1}.

Despite the fact that there are no reports in Latin America of effects on wild species exposed to NP, reported concentrations in surface water range from 12.6 to 2390 µg L^{-1}, significantly higher than reported concentrations where it already causes an effect, so based on these environmental levels, it is suggested that there is an ecological risk in this geographic region, implying the need to explore these effects particularly in aquatic species due to the ecological importance they represent.

4.2. Human risk to NP and implications in Latin America

The present review of the literature found no studies linking human health risks to exposure to NPs. However, research focuses on the effects of human cell lines, it has been reported apoptosis provoking morphological distinctive changes in different types of cells like thymocytes, PC12 cells, sperm cells and testicular Sertoli cells (Kim et al., 2007), as well as prostatic cell lines and ovaries under a depending activation process ADAM17 (Urriola-Munoz et al., 2018).

Cytotoxicity effects in Sertoli cells have been explored and it has been found that the exposure to 20-30 µM of NP for 24 hr causes a decrease in cellular viability provoking cellular death via apoptosis and autophagy (Duan et al., 2016). Neural mother cells have been studied after being exposed to 4-NP by 24 hr finding that cellular growth is inhibited in a concentration dependent manner and inducing apoptosis (Kudo et al., 2004).

Bioaccumulation has been demonstrated in humans, seven different compounds of alkylphenol have been found in adipose subcutaneous tissue in humans, being the NP the most common (Ferrara et al., 2011). Even though there are few studies in this regard, it has already been found NP accumulation in adipose tissue in humans and cadavers with concentrations of 57 and 37 ng g^{-1} respectively (Lopez-Espinosa et al., 2009).

Regarding NP exposure in humans, it in humans is mainly through consumption of polluted water and foods (Careghini et al., 2015). Due to its high stability and solubility in lipids, NP may be accumulated in fish internal organs reaching concentrations of 10 to 100 times higher than concentrations found in the environment (Kim et al., 2007). This originates an important concern because it could be easily transmitted to humans through the food chain (Chang et al., 2019). Likewise, variable concentrations of NP found in multiple foods (independent of the fatty content and packing materials) imply that NP is introduced in different production stages. This may be because of its use as a non-ionic surfactant and/or emulsifier in disinfectants, cleaning products and pesticides (Kawamura et al., 2017; Mao et al., 2012). Therefore, it is important to detect its presence in seafood, beverages, egg, vegetables, fruit, meat, rice, commercial milk, among others (Sise and Uguz, 2017). Variable concentrations of NP have been reported previously; for example, in packaged food concentrations from 0.1 to 19.4 µg Kg^{-1} (7.5 µg NP per day) (Guenther et al., 2002), in commercially available fruits, cereals, and vegetables from 10 to 71 µg Kg^{-1} (Gyllenhammar et al., 2012), in packaged fruits and vegetables from 14.5 to 48 µg Kg^{-1} (Cacho et al., 2012), in local fruits and vegetables markets from <0.3 up to 11.0 µg Kg^{-1}, in lettuce and cabbage leaves from 1.18 to 6.95 µg Kg^{-1} and in roots from 339.2 to 926.9 µg Kg^{-1} (Dodgen et al., 2013) and in stew from 4.32 to 167 µg Kg^{-1} (Hao et al., 2018). Concentrations in meat and seafood have also been reported; for example, concentrations in meat and seafood from supermarkets from <0.05 to 55.98 µg Kg^{-1}, in edible marine species from 5 to 1220 µg Kg^{-1} (Ferrara et al., 2011), in aquatic organisms from 122 to 2380 µg kg^{-}

^{1} (Diehl et al., 2012) and up to 918 µg Kg^{-1} in grains and can food (animal and seafood origin) (Chang et al., 2019).

The main exposure pathway in infants is through breast milk intake. Previous investigations have found up to 32 ng mL^{-1} of NP in breast milk in Italian women (Ademollo et al., 2008), from 17 to 11.6 ng mL^{-1} in women from Taiwan (Lin et al., 2009) and up to 47 ng mL^{-1} in women from Turkey (Sise and Uguz, 2017). The intake of NP of children exclusively fed with breast milk in Germany is approximately 1.4 µg per day (Guenther et al., 2002) and children with a mixed diet are approximately from 0.23 to 0.65 µg Kg^{-1} (Raecker et al., 2011). A child´s diet includes also cow milk so it is important to consider it. It has been reported concentrations of NP in commercial cow milk from 2.9 to 8.9 ng g^{-1} in Taiwan (Lin et al., 2009), 0.3 ng g^{-1} in Germany (Guenther et al., 2002) and 1.0 ng g^{-1} in Japan (Otaka et al., 2003).

In Latin America, the information about concentrations of NP in food and water drinking is limited, without mentioning the limited information available on the potential risk after its consumption. Previous studies in Mexico and Brazil have reported maximum concentrations of 6.08 and 1.2 µg L^{-1} in drinking water. No studies about nonylphenol in foods in Latin America were found, despite the lack of evidence in this geographical area, exposure is genuine and control and monitoring measurements of the main sources of contamination are needed. No studies about nonylphenol in foods in Latin America were found, despite the lack of evidence in this geographical area, exposure is genuine and control and monitoring measurements of the main sources of contamination are needed.

5. Regulation for the use of Nonylphenol and their ethoxylates

Strategies and regulations have been developed to urgently deal with EDCs, among them NP (**Table 2**). For example: (i) The EU restricted its use with the Directive 2003/53/EC which establishes that it must not be commercialized or used as a substance in mixtures in quantities equal or higher than 0.1% in mass of NP or 1% in mass of NPE (Union, 2003). Moreover, the Directive 775/2004 (02/2076) prohibited its use for the elaboration of pesticides (Union, 2006), (ii) The Water Framework Directive of the European Union with the Directive 2013/39/EU has listed NP as a priority pollutant and allows a maximum concentration in water of 2 µg L^{-1} (Union, 2013), (iii) the governing body of the Convention for the Protection of the Marine Environment of the Baltic Sea classified the NP as dangerous according to the action plan for the conservation of the Baltic Sea (UNEP, 2015), (iv) EPA recommends concentrations of NP in freshwater to be lower than 6.6 µg L^{-1} and in saltwater lower than 1.7 µg L^{-1} (EPA, 2005), (vi) The Canadian Act of Environmental Protection added this substance to the 1999 list of toxic substances (Canada, 1999).

These restrictions summed with the impacts previously discussed are forcing the academic and industrial community to develop strategies to substitute the NPE to minimize health and environmental risks. Currently, Latin America does not rely on any regulation in this regard, therefore it is necessary to increase environmental and health authorities that create and implement regulations and restrictions to reduce environmental impacts that may represent a risk for public health (Peña-Guzmán et al., 2019). The Rotterdam Convention, to which all Latin American countries are parties, can serve as a basis for the establishment of maximum permissible limits for NP as a severely restricted compound and to adopt the concentrations proposed by the EU or EPA in surface water (UNEP, 2016).

6. Environmental levels of NP in the water of Latin America compared to other regions.

Even though the presence of EPs like the NP is known worldwide there is a gap of knowledge about its distribution in some geographic areas like Latin America (Llorca et al., 2017). A compilation of studies of NP concentrations in different water bodies worldwide is shown in **Table 3**. Even though there are similitudes between concentrations of NP found in different regions, it is important to acknowledge that the matrixes are different. For example, while in Mexico there are concentrations of NP in surface water up to 13.02 µg L^{-1}, similar to concentrations found in wastewater from the United States, Europe, and Asia. In addition, previous studies in Argentina have found important concentrations in surface water and wastewater which are up to 2,000 times more than those allowed by the European Union (2 µg L^{-1}) and 200 times more than the recommended by the EPA (6.6 µg L^{-1}). Moreover, maximum concentrations found in wastewater from Latin America are 3 times higher than those found in the United States and 8 times higher than those found in Europe. On the other hand, maximum concentrations found in surface water in Latin America were 57 times higher than those found in Asia and 915 times higher than those found in South Africa. This reinforces the need for regulations in the usage and disposal of NPE in Latin America. The lack of information in Latin American countries such as Cuba, El Salvador, Haiti, Honduras, Nicaragua, Panama, Paraguay, Peru and the Dominican Republic can be attributed to the high cost and lack of analytical infrastructure for quantification (Peña-Guzmán et al., 2019). It is important to implement a strategy that includes continuous monitoring and the implementation of regulations for the environmental impact assessment and the possible public health risks in Latin America.

7. Technological development for substitution of NPE in detergents

NPE is substituted usually by ethoxylated alcohols; less effective surfactants but safer for the environment because of its fast biodegradation. However, some studies suggest that biodegradation byproducts have low solubility and are absorbed in residual sludges (Soares et al., 2008). On the other hand, natural surfactants may also substitute alkylphenol ethoxylates; for example, alkyl polyglucosides (APGs) are nonionic surfactants produced by removable raw materials like corn, potatoes, wheat and coconut oil (Pantelic and Cuckovic, 2014). This compound has advantages over other surfactants: appropriate critical micellar concentration, ability to form microemulsions, proper foaming power, stable at different pH values, biodegradable, low aquatic toxicity and favorable dermatological properties (Holmberg, 2001; Jurado et al., 2012; Pantelic and Cuckovic, 2014; Qin et al., 2006). Due to its natural origin and the excellent physical and environmental properties, the APGs may be used in domestic and industrial applications (Rios et al., 2016). Even though this compound has some advantages it is still a challenge to persuade companies to replace conventional surfactants because of the higher costs of natural surfactants (up to 50 times higher than synthetic surfactants) (Deleu and Paquot, 2004).

8. Conclusions

Emerging pollutants present a new global challenge about water quality with potentially important threats to human health and ecosystems. The importance of this issue is such that the United Nations included it in the Objectives of Sustainable Development as Goal No. 6 (Ensure access to water and sanitation for all). There is a lack of information about EPs occurrence in some regions of the world, significantly in developing countries such as the Latin American countries. This review identified that EPs occurrence has a strong relation with the lack of legislation, high analysis costs in environmental matrixes and limited information about probable effects. This demonstrates that NP exposure may cause adverse health effects at any level of the trophic network, and in some species, these effects can occur at very low concentrations. Nevertheless, it is necessary to adopt good practices and environmental policies to mitigate potential risks in human and ecological health based on the approach of precautionary principles, based on evidence of possible harm without requiring absolute scientific certainty. The example of NP showed in this review, highlights the lack of regulation in Latin America regarding EPs, which results in pollution of wastewaters, effluents, rivers and drinking water. The development of a coordinated, integrated and collaborative strategy by countries in Latin America for the consumption, discharge, and disposition of these compounds is fundamental. This could contribute to the reduction and prevention of negative impacts that EPs cause in the environment and public health. It is imperative to determine potential effects, occurrence and concentration levels to improve regulations of these pollutants soon.

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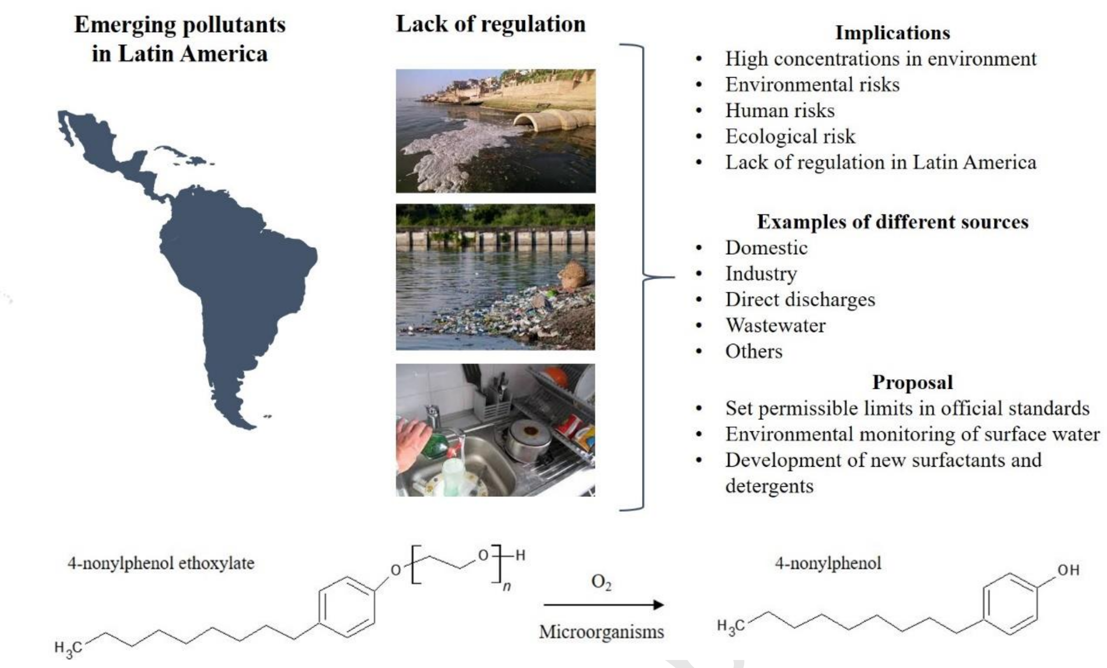

Implications

- High concentrations in environment
- Environmental risks
- Human risks
- Ecological risk
- Lack of regulation in Latin America

Examples of different sources

- Domestic
- Industry
- Direct discharges
- Wastewater
- Others

Proposal

- Set permissible limits in official standards
- Environmental monitoring of surface water
- Development of new surfactants and detergents

Table 1. Comparison of regulations of emerging pollutants in the United States and the European Union

Region	Fundamental Law	Number of EPs	Supportive Agencies
United States	Safe Drinking Water Act	109	EPA
			FDA
			EDSTAC
			Global Water Research Coalition
European Union	Water Framework Directive	1036	EQSD
			Groundwater directive
			REACH
			Collaborative Project SOLUTIONS
			NORMAN

* EPs: emerging pollutants, EPA: Environmental Protection Agency; FDA: Food and Drug Administration; EDSTAC: Endocrine Disruptor Screening and Testing Advisory Committee; EQSD: Directive on Environmental Quality Standards; REACH: Registration, Evaluation, Authorisation and Restriction of Chemicals; NORMAN: European Monitoring Network.

Table 2. Regulations of nonylphenol and its ethoxylates in different regions.

Region	**Directive**	**Observations**
European Union	2003/53/EC	Must not be commercialized or used as a substance in mixtures in quantities equal or higher than 0.1% in mass of NP or 1% in mass of NPE
	775/2004 (02/2076)	Prohibited for the elaboration of pesticides
	2013/39/EU	Listed as a priority pollutant and allows a maximum concentration in water of 2 µg L^{-1}
United States	EPA	Recommends concentrations of NP in fresh water to be lower than 6.6 µg L^{-1} and in saltwater lower than 1.7 µg L^{-1}
Canada	CEPA	Listed as toxic substance.
Signatory countries	Rotterdam Convention	Severely restricted compound

EPA: Environmental Protection Agency, CEPA: Canadian Act of Environmental Protection, NP: nonylphenol, NPE: nonylphenol ethoxylates

Table 3. Concentrations of NP in water samples worldwide.

Region	Country	Sample	n	Min	Median	Max	Reference
Latin America	Mexico	Surface water	8	830	3.05	12.61	(Vargas-Berrones et al., 2020)
	Mexico	Wastewater	12	<LOD	3.79	12.20	(Vargas-Berrones et al., 2020)
	Mexico	Drinking water	5	<LOD	2.48	6.08	(Vargas-Berrones et al., 2020)
	Argentina	Surface water	14	1,730	2,020	2,390	(Babay et al., 2008)
	Argentina	Wastewater	6	2,390	2,550	2,680	(Babay et al., 2008)
	Brazil	Surface water	5	ND	ND	1,240	(Jardim et al., 2012)
	Brazil	Drinking water	5	ND	<LOQ	<LOQ	(Jardim et al., 2012)
	Brazil	Surface water	2	<LOD	<LOD	<LOD	(Raimundo, 2011)
	Mexico	Surface water	1	0.089	-	0.655	(Félix–Cañedo et al., 2013)
	Mexico	Drinking water source	1	0.001	-	0.047	(Félix–Cañedo et al., 2013)
	Mexico	Surface water		0.930	-	7.6	(Belmont et al., 2006)
	Mexico	Wastewater		0.75	-	13.02	(Belmont et al., 2006)
	Colombia	Drinking water source	5	ND	ND	ND	(Martinez and Peñuela, 2013)
US	United States	Wastewater (influent)	8	265	745	745	(Loyo-Rosales et al., 2007)
	United States	Wastewater (effluent)	8	0.42	5.97	8.42	(Loyo-Rosales et al., 2007)
European	Spain	Surface water	6	0.5	2.0	36.0	(Martín et al., 2014)
	Spain	Wastewater	4	0.6	142	289	(Martín et al., 2014)
	Italy	Wastewater	8	0.37	0.515	0.700	(Loos et al., 2007)
	Italy	Drinking water	35	<7.7	0.015	0.084	(Maggioni et al., 2013)
	Belgium	Wastewater	10	250	745	2.5	(Loos et al., 2007)
Asia	China	Surface water	15	0.1	1.3	7.3	(Shao et al., 2005)
	China	Drinking water	15	0.01	0.05	2.7	(Shao et al., 2005)
	Korea	Surface water	18	0.01	0.9	41.3	(Li et al., 2004)
Others countries	Iran	Wastewater	9	0.42	0.81	2.12	(Bina et al., 2018)
	South Africa	Surface water	7	0.38	1.65	2.61	(Sibali, 2010)

*Units: µg L^{-1}, LOD: limit of detection, LOQ: limit of quantification, ND: not detected

Highlights

- There is a gap in the knowledge about emerging pollutants in Latin America.
- Lack of legislation and high analysis costs are the main causes of its occurrence.
- An example evidences this situation which results in pollution of water resources.

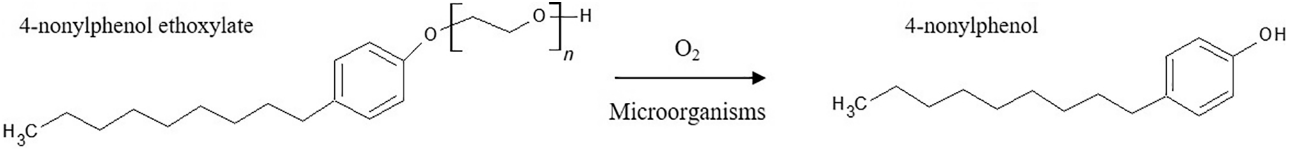
4-nonylphenol ethoxylate
O_2
Microorganisms
4-nonylphenol
OH
H3C
O
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Figure 1