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Removal of emerging contaminants from the environment by adsorption

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ABSTRACT

Emerging contaminants (EC's) are pollutants of growing concern. They are mainly organic compounds such as: pesticides, pharmaceuticals and personal care products, hormones, plasticizers, food additives, wood preservatives, laundry detergents, surfactants, disinfectants, flame retardants, and other organic compounds that were found recently in natural wastewater stream generated by human and industrial activities. A majority of ECs does not have standard regulations and could lead to lethal effects on human and aquatic life even at small concentrations. The conventional primary and secondary water treatment plants do not remove or degrade these toxic pollutants efficiently and hence need cost effective tertiary treatment method. Adsorption is a promising method worldwide for EC removal since it is low initial cost for implementation, highly-efficient and has simple operating design. Research has shown that the application of different adsorbents such as, activated carbons (ACs), modified biochars (BCs), nanoadsorbents (carbon nanotubes and graphene), composite adsorbents, and other are being used for EC's removal from water and wastewater. The current review intends to investigate adsorption process as an efficient method for the treatment of ECs. The mechanism of adsorption has also been discussed.

1. Introduction

Recently water availability is threatened due to increased anthropogenic pollutants from industrial and non-industrial sectors. About 2 million tons of sewage is being discharged into fresh water every day (Norman, 2017). Annual report of the UN estimated that 1500 km^3 of wastewater is generated on average. This value is about six times the existing river waters in the world (UNESCO, 2003). Approximately 90% of water supplies in cities are contaminated, of which 70% are household sewage and 33% is industrial wastewater which is released directly into lakes and rivers without prior treatment (Geissen et al., 2015).

Emerging contaminants (ECs), are unregulated or not completely regulated compounds even in the most developed countries, and that can be a hazard to the surroundings and human health (Esplugas et al., 2007; La Farré et al., 2008). Emerging contaminants are different compounds such as, pharmaceuticals and personal care products (PPCPs), contrast media, plasticizers, food additives, wood preservatives, laundry detergents, surfactants, disinfectants, flame retardants, pesticides, natural and synthetic hormones, and a few disinfection by-products (DBPs) (La Farré et al., 2008), etc have been discharged by house-holds and industries. Several compounds or their metabolites end up in the environment. Due to the rising awareness of the influence of these pollutants on environmental water bodies, treatment of ECs is considered important (Chaukura et al., 2016). These ECs however can be found in low concentrations into water and wastewater treatment plants. These compounds may occur naturally or synthetically and usually go undetected in the environment (Norman, 2017, Petrie et al., 2017; Sorensen et al., 2015). The ecotoxicological effects, fate, and behavior of ECs are not clearly evident, as it is not presently included in international regular monitoring program (Geissen et al., 2015; La Farré et al., 2008).

It was reported that presence of pharmaceutical, pesticides, plasticizers, hormones, in waters may generate high risks to human health due to its bioaccumulation (Jean et al., 2012), and also creating microbial drug resistance (Andersson and Hughes, 2012; Merlin et al., 2011; Le-Minh et al., 2010). Bromoform, chloroform, diclofenac, caffeine, ibuprofen, naproxen, methyl dihydro jasmonate, galaxolide, butylated hydroxytoluene, and butylated hydroxyanisole were found in irrigation water using for crops, and also several of these compounds were afterwards found in the plants (Calderón-Preciado et al., 2011). Hormones act as endocrine disruption agents presenting potential impact in the reproductive health and survival of different fishes, and impacting the reproductive health and sustainability of indigenous populations of fishes (Mills and Chichester, 2005). All these pollutants cited above are different classes of EC´s that are hazardous even at very

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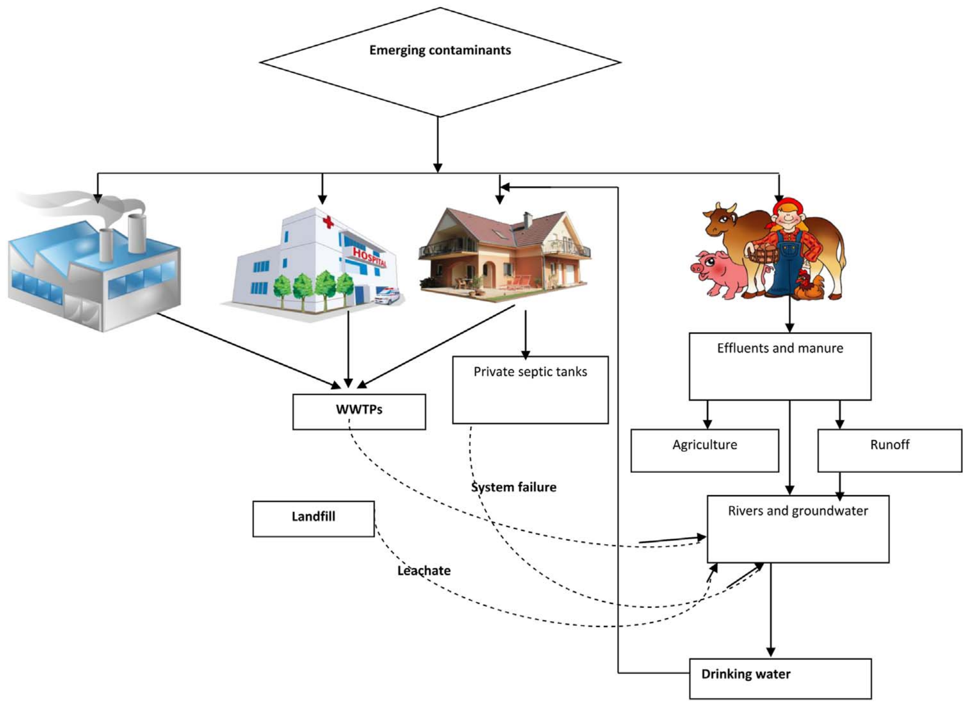

Fig. 1. Sources of emerging contaminants into the environment.

low concentration levels due to high influence onto live organs and its high environmental persistence (Barrios et al., 2015). Pharmaceutical, hormones and personal care products (PPCPs) are endocrine disrupters (Rovani et al., 2014), which hamper the natural hormonal functions particularly in fish and humans (Mills and Chichester, 2005). The treatment of water containing ECs is emergent due to lack of contaminant removal and/or treatment facilities (Babaei et al., 2016; Saucier et al., 2015; dos Reis et al., 2016). Investigation on ECs is expanding and is encouraged by the progress in finding the appropriate method for wastewater treatment (Arp, 2012; Takdastan et al., 2016; Fernandez et al., 2015; Fischer et al., 2017).

EC's are generally found in industrial and municipal wastewater treatment plants cannot be easily remediated through conventional treatment technologies (Rivera-Utrilla et al., 2013). They find way into the environment via several pathways and the same is diagrammatically shown in Fig. 1. A conventional biological treatment facility may enhance the concentration of some ECs depending on the micro pollutant concentration (25–100%) (Sellaoui et al., 2017a; Carmalin et al., 2016). The different effluent treatment methods that are in practice are presented in Fig. 2 (Carmalin et al., 2016; Acero et al., 2012; Grassi et al., 2012). Most of these treatment methods are not techno-economically feasible for field implementation. These developed methods have some problems due to the complex procedures, maintenance, high investment cost, toxic sludge generation, toxic by-product generation, etc (Thiebault et al., 2015; Attia et al., 2013). Therefore, effective treatment process for removal of ECs is requisite.

Of all treatment methods that have been developed, adsorption is the one most pertinent and promising method for removing organic and inorganic micro pollutant's (Umpierres et al., 2017; Saucier et al., 2017). Most often, the process is used to remove synthetic macrobiotic compounds during drinking water treatment. The process has copious advantages (i) simple to operate and to design; (ii) handling micro level of pollutants; (iii) vigorous continuous and batch processes; (iv) toxicity removal; (v) low investment cost; (vi) environmentally benign; and (vii) probability of adsorbent reuse and regeneration (Torrellas et al., 2016a; Bhatnagar and Anastopoulos, 2017). Adsorption got its prominence since it is effective in treating the dissolved pollutants that remain even after chemical oxidation processes or biological treatment (Fagan et al., 2016; He et al., 2016; Xu et al., 2016). However, the batch reactors involving adsorption process require secondary sludge removal (Attia et al., 2013). This could be solved by using hybrid systems (Shanmuganathan et al., 2017).

The exploration for new adsorbents has been intensified in recent years. Removal of PPCPs such as naproxen (NPX) (Hasan et al., 2012, 2013), clofibric acid (Hasan et al., 2012, 2013), bisphenol-A (BPA) (Park et al., 2013; Qin et al., 2015), tetracycline antibiotic (Takdastan et al., 2016) and diclofenac (Hasan et al., 2016) using adsorption has been recently reported. The present review explains the strategies involved in wastewater treatment using adsorption for the removal of ECs. Furthermore, the factors such as equilibrium time, adsorption capacities, and removal efficiency of ECs, makes it appropriate to be considered as a green process.

2. Adsorbents for removal of emerging contaminants

Numerous literature reviews pertaining to the use different adsorbents for wastewater organic pollutant removal have been published over the last few decades (Hamdaoui and Naffrechoux, 2009). Treatment of various ECs from water and wastewater sludge (Barceló, 2005; Grassi et al., 2012), paper mill wastewaters (Latorre et al., 2005), sediments and soil (Kuster et al., 2005), fragrance materials (Simonich, 2005), pesticides (Hernando et al., 2005), human pharmaceuticals from environment (Brooks and Huggett, 2012) have been investigated. The immunochemical assays for removal of contaminants from industries (Estevez et al., 2005a), PPCPs (Estevez et al., 2005b; Wang et al., 2015) have been determined. The adsorbent materials used include zeolites (Suna et al., 2017), organic soils (Pignatello, 1998), organic carbon framework (Liu et al., 2017), metal organic framework (Yang et al., 2017), activated carbon (Song et al., 2017), biochar (Ahmed et al., 2016), activated hydrochars (Fernandez et al., 2015), carbon nanotubes (Ncibi and Sillanpää, 2017), graphenes (Zambianchi et al., 2017), composites with activated carbon (Shirmardi et al., 2016) and mesoporous nanocomposite of polymer and clay (Pinto et al., 2016).

Various nanomaterials have been used as effective adsorbents for the sorption of ECs from effluents (Arshadi et al., 2017; El-Saliby et al., 2008; Kaur et al., 2017). Graphite is exfoliated by oxidizing agents to produce layers of graphene (Chowdhury and Balasubramanian, 2014); methane and other hydrocarbons that are chemically deposited by the