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Emerging Pollutants Remediation Water Systems

Biomass-Based Technologies

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1.1 Introduction

Emerging Pollutants (EPs) or pollutants of emerging concern are labels for a class of chemicals that are intrinsically detrimental to the environment but not essentially lethal [1]. This assemblage of chemicals incorporates an extensive assortment of substances including human and veterinary drugs, personal care products (PCPs), disinfection by-products (DBPs), polycyclic aromatic hydrocarbons (PAHs), perfluorinated compounds (PFCs), heavy metals, surfactants, pesticides, flame retardants, algal contaminants and hormones besides numerous other groups of chemicals. Throughout the preceding few decades, several investigative programmes have been going on to explore and examine the existence and fate besides ecotoxicology, of a lot of emerging pollutants (EPs). The EPs are sampled out from soils [2], sediments [3], wastewaters plus other aquatic

Aquatic Environmental Bioengineering: Monitoring and Remediation of Contamination, First Edition.
Rouf Ahmad Bhat, Mohammad Yaseen Mir, Gowhar Hamid Dar and Moonisa Aslam Dervash.
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environs [4]. As far as distribution of EPs is concerned traces of these have been reported from practically all the domains of our environment [5]. These EPs have also been found in the bodies of newborn infants proving their grave peril to the well-being of humans and other organisms alike. Normal treatment procedures are incompetent to eliminate these EPs, resulting in their discharge into receiving aquatic environments. However, a thorough and all-encompassing scientific research concentrated on the investigation of EPs source, presence, effects; and its treatment methods are not well established [6].

EPs are highly reactive and mobile due to which its elimination from aquatic settings is often an uphill task. It is pertinent to mention that minute quantities of EPs can pollute a significant bulk of aquatic ecosystems. Furthermore, EP-laden wastewaters can't be efficiently treated by already existing treatment operations which results in an augmented jeopardy due to their persistence in the environs [7, 8]. Consequently, the existence of EPs in wastewater management facilities is gradually developing into an unintended birthplace of severe contamination hazard to the waterways. Therefore, developing state-of-the-art procedures for management of waters tainted with EPs is an unrelenting and everlasting requisite. In this concern, a number of techniques have been explored and developed for eliminating and mitigating the deleterious effects of EPs on aquatic ecosystems through various physical, chemical and biological approaches. Certain methods are working well, however are costly, while other methods are equally capable and economical but detrimental to the environment. In this backdrop, water management techniques using biomass and related derivatives as a chief element are prospective of remediating the predicament of a number of EPs (Table 1.1). The biomass-based technologies are more efficacious, economical as well as eco-friendly as compared to existing treatment methods. This chapter delivers an overall gist of diverse pioneering biological methods for eliminating an array of EPs as well as outlining forthcoming exploration trends.

Table 1.1 Biosorption of varied biomasses to eliminate certain EPs from contaminated environments.

Emerging pollutant	Biosorbent	Reference
Pharmaceuticals		
• Paracetamol	Sugarcane bagasse	[9]
• Metronidazoles	Siris seed pods	[10]
Endocrine-disrupting chemicals		
• Nonylphenol	*Rhizopus arrhizus*	[11]
Radionuclides		
• Uranium VI	Wheat straw	[12]
• Cesium	*Citrobacter freudii* (bacteria)	[13]
	Fusarium Sp. (fungi)	[14]
	Basil seeds	[15]
	Walnut shells	[16]
Algal toxins		
• Microcystin-LR	Peat	[17]

1.2 Adsorption-Based Remediation

This water treatment method characterizes a vital part of EP remediation systems. Four major processes are discussed here, viz. sorption, adsorption, biosorption and bioadsorption. The terms adsorption and adsorbent refer to the sorbing substances that aren't biomass-based. This involves activated carbons and biopolymers (biomass derivatives), as well as silica, zeolites, clays and synthetic polymers. The terms biosorption and biosorbent (raw or pretreated) encompass the application of dead ("bioadsorption") and standing biomass ("passive" biosorption and/or "active" bioaccumulation).

1.2.1 Biomass

Several types of biosorbents "plants, algae, bacteria, fungi, yeasts" have been quantified in the sources over many years due to their potential for eliminating diverse toxic pollutants. Although EPs are discovered in diverse environments and pose a number of severe undesirable effects on our planet, they aren't presently counted in standard environmental assessment options. There exists a knowledge gap concerning the level of research conducted on the already existing pollutants and the newly emerging pollutants. A scientific supposition stating that conventional contaminants hold greater and confirmed toxicity threat in contrast to the EPs isn't correct at all times. In fact, during the last few years research investigations vis-à-vis EPs have increased exponentially [18].

1.2.2 Terrestrial and Marine Bioresources

Azoimide (hydrazoic acid) is an extremely toxic substance polluting hospital wastes [19]. In order to find a viable way out to deal with this toxic substance, its removal by powdered almond integument from contaminated waters was carried out. It was found that 1 g of almond biomass removed 45 mg of the azoimide toxin [20]. The release of hazardous wastes from nuclear power plants has been a serious cause of concern. To find a solution, investigators explored the adsorption efficacy of cactus fibers (*Opuntia ficus*) to get rid of uranium VI from discharged nuclear wastes and they were quite successful in it [21]. Similarly, the potential of *Posidonia oceanica* for removing surfactants from aqueous solutions was evaluated. The marine algae *Padina pavonia* was used as a biosorbent for the remediation of uranium (VI) from wastewaters. It was discovered that the marine biomass was effective in eliminating uranium with 98% effectiveness [22].

1.2.3 Agro-Industrial Wastes

In Turkey, the biosorption of Gallium III from polluted waters was accomplished via tea waste. It was discovered that this tea waste was effective in removing 77.4% of waste present in the solution [23]. Rice straw was utilized as a biosorbent to eliminate pharmaceuticals [24] which are often identified in wastewaters [25]. The findings confirmed that rice straw was able to remove the pharmaceuticals by means of adsorption. Similarly, a research group from Brazil was successful in removing Diclofenac from aqueous solutions via Isabel grape bagasse [26].

1.2.4 Activated Carbons (ACs)

1.2.5 Bioresources

Various biological precursors are used for manufacturing extremely absorbent activated carbons which can further be used for tackling EPs. An innovative AC was manufactured using Artemisia vulgaris for removing the widely used drug Ibuprofen from aqueous solutions. It was established that A. vulgaris-derived AC removed 17 mg/g of the drug [27]. ACs have also been produced from the leaves of the date palm (*Phoenix dactylifera*). The ACs formed from it were used for elimination of an antibiotic, ciprofloxacin, from contaminated waters [28].

1.2.6 Agro-Industrial Wastes

Chemically activated biochar formed from loblolly pine chips was used for the adsorption of several EPs from contaminated waters. The adsorption findings revealed an enhanced capacity for removing EPs [29]. In another investigation researchers examined the potential of ACs made from sesame stalk derived for removing Phenanthrene. The adsorbent displayed a remarkable efficacy to remove this EP [30].

1.2.7 Activated Sludge (AS)

Activated sludge is often useful in wastewater management plants. Huge quantities of AS are generated regularly, therefore its utilization for removing EPs from aqueous environs has been deliberated upon. Perfluorocarbons are incessant EPs and for tackling this crisis, AS was used in aqueous solution. The results showed that AS was capable of eliminating the EPs with a higher efficacy as compared to other techniques [30].

1.3 Bioremediation

Bioremediation utilizes the intrinsic abilities of particular plants and microbes to biologically eliminate or stop the action of lethal substances from polluting our environment. Bioremediation is also useful to remove EPs from aquatic environs through plants (i.e. phytoremediation) and microbes (i.e. microbial remediation).

1.3.1 Phytoremediation

Callus cultures of the poplar tree (*Populus nigra*) have been inspected for removal of a commonly used drug, Ibuprofen. It has been stated that Ibuprofen was eliminated entirely by poplar cells [31]. In another research vetiver grass was reported to be able to successfully remove cesium and strontium from artificially polluted waters and also from nuclear wastes [32]. Similarly, researchers were successful in using *Eleocharis acicularis* for removal of toxic metals from polluted waters in Japan [33]. Water hyacinth biomass was used for the removal of radioactive waste consisting of cesium and cobalt residues. The chief findings indicated that the Cs uptake by this macrophyte increased with increased biomass amount and sun contact [34].

1.3.2 Constructed Wetlands (CWs)

CWs are fundamentally advanced treatment structures to aid in the natural process of bioremediation. Significant research and development efforts have been carried out using CWs to get rid of EPs in a natural and eco-friendly way. CWs have been used for bioremediation of various EPs such as pharmaceuticals, personal care products, pesticides etc. The removal efficacy varies with the type of EP. Also, the bioremediation processes in CWs include coordinated biodegradation, biosorption and photodegradation [35].

1.3.3 Microbial Remediation

Microbes have been equally useful in bioremediation of EPs as with any other organism. Fungus T. versicolor was used to get rid of many classes of EPs including pharmaceuticals, brominated flame retardants (BFRs) and UV filters. Dioxins and dioxin-like compounds were removed from wastewaters using three brown-rot fungi "*Aspergillus aculeatus*, *A. flavus*, *A. fumigatus*" and one white-rot fungus "*Phanerochaete chrysosporium*" [36]. In the same way, a metal-resistant bacteria, Bacillus cereus, was successful in bioremediation of waters polluted by "decabromo diphenyl ether", which is a poisonous polybrominated flame retardant [37]. Thankfully, in our environment, the degradation of contaminants is typically by reason of mutual or synchronized enzymatic activities of numerous microbes, mainly bacteria, microfungi and microalgae. These microbes play a vital role in cleaning up environments polluted by humans.

1.3.4 Biocoagulants and Bioflocculants

Coagulation and flocculation are one of the central steps in wastewater treatment plants (WWTP). As mentioned earlier, WWTP are also developing into an additional source of EPs in water bodies. Numerous investigations have deliberated upon the generation of biomass-based flocculants and coagulants to remove EPs. As a result, many impending bioresources have been investigated to generate recyclable and economical flocculating/coagulating agents to deal with EPs [38]. Figure 1.1 represents a common three-phase extraction and purification arrangement for biocoagulants, as shown by Yin [39]. Moringa tree (*Moringa oleifera*) seeds have demonstrated a remarkable coagulation activity to remove surfactants from contaminated waters with 80% efficiency predominantly via the biocoagulation/bioflocculation method [40]. A biopolymeric flocculant, "MBF-5" made from the *Klebsiella pneumoniae* strain was tested to tackle pathogenic, disinfection-resistant Acanthamoeba cysts from wastewaters [41]. A whopping rate of 79.4% flocculation of this pathogen was attained using the *K. pneumoniae*-based bioflocculant [42]. Sulfamethoxazole, a widely used antibiotic, is one of the most widely found drug products in wastewaters [43]. This EP was removed with 53.27% efficiency using bioflocculant MFX, produced from Klebsiella sp [44].

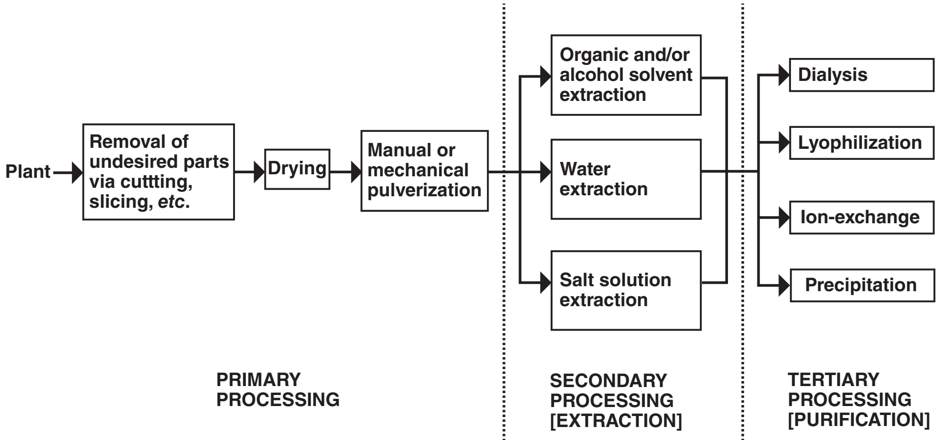

Figure 1.1 Steps involved in preparation of plant-based coagulants [39].

1.4 Multi-Element Water Treatment Process

In this section, multi-element water management methods concerning the application of biomass-based techniques for EPs remediation will be elaborated. The chief objective is to demonstrate the merging of decontamination techniques as a central approach to maximize the benefits.

1.4.1 Membrane Bioreactors (MBRs): Biodegradation and Membrane Filtration

The MBR technique for wastewater management is a precisely guaranteed method. This technique combines biodegradation with membrane filtration of wastes and can be used effectively to get rid of EPs from aquatic environments [45]. The chief leads of MBRs are improved treated wastewater quality and a reduced quantity of sludge output besides advanced functioning to treat EPs with increased elimination efficacy [45-46]. In Japan exclusion of EPs (pharmaceuticals) from wastewaters was achieved through MBRs. The tested MBRs displayed superior EP removal levels for the scrutinized drugs [47]. In a different research study, the removal of two perfluorinated compounds was achieved using activated carbon and the MBR system with an efficiency of 90% [48].

The biological combination is one of the highly noteworthy methods in the field of EP treatment. This association is highly versatile, environmentally sustainable, besides being economical. In every wastewater treatment plant, both adsorption and biodegradation play a major role in removal of contaminants. Adsorption aids in biodegradation which helps in total elimination of EPs. Biodegradation helps in adsorption of pollutants in addition to removing contaminants from the aqueous solution which are capable of constraining microbial growth or action. In a study, biosorption and biodegradation were helpful in removing Triphenyltin, an extremely poisonous EP with the aid of the bacteria *Brevibacillus brevis*. This bacterium adsorbed 97% of the toxin; while as for biodegradation, an elimination efficacy of 60% was recorded [49].

1.4.2 Activated Carbon and Ozone

Water treatment techniques developed from the linking of adsorption and ozonation have successfully demonstrated the removal of numerous kinds of contaminants [50]. This combined method of enhancing removal efficiency demands to midpoint on a particular contaminant and check its elimination levels by means of specific as well as collective approaches. It has been proven that the combination of ozonation and adsorption onto activated carbon is an efficient method to decrease the concentration of micro-pollutants in contaminated waters [51,52].

1.5 Views and Recommendations

By and large, the research endeavours in the domain of water and wastewater management are based on the development of competent, economical and environmentally friendly approaches. With respect to biomass and its eminent benefits (i.e. renewability, accessibility, incredible generation rates, plus biochemical abundance), any wastewater treatment technique using biomass or its derived products as a primary constituent in the treatment method needs to be adaptable and to come with additional improvements. Accordingly, biomass as the nucleus of any decontamination approach will facilitate investigators to pursue the accurate orderliness of importance in their approaches, which are: being environmentally friendly, efficient and economical. Certainly, in formulating a sustainable EPs elimination technique, we can't rescue the environs by substituting one type of contamination with a new one. In this scenario the usage of biomass is highly valuable due to its varied decontamination processes. As soon as the ecological facet of the biomass-centered method is assured, the spotlight will be on optimizing the water treatment procedure itself. Numerous choices are available to deal with EPs because of the accomplishments of worldwide research groups. However, the costs need to be appropriated to adjust the decontamination processes realistically. In this regard, the utilization of biomass is exceedingly profitable as a renewable and economical alternative.

1.6 Conclusion

In facing the whole host of organic and inorganic contaminants of emerging concern that are hazardous to the aquatic environs, multiple research studies were conducted to alleviate this grave issue. Biomass-centered cleansing approaches are among the most remarkable water treatment methodologies. An assortment of resources was explored globally for the expansion of competent, environmentally friendly methods to fight the menace of EPs. In this context, biomass-based remediation techniques hold an important collection of techniques for EP elimination from aquatic environs. Nevertheless, it is necessary to mention that very few of the reviewed research findings incorporated a commercial application. Bioadsorption onto bioresources, organic wastes, and derived activated carbons and biopolymers were utilized for the management of wastewaters containing radioactive wastes, pharmaceuticals, polyaromatic hydrocarbons etc. with encouraging outcomes. Further methods to deal with the subject of water pollution by EPs comprise bioremediation. This is centered on the ability of plants and microbes to disintegrate, amass, diminish, precipitate or restrain noxious pollutants. In addition, numerous research activities projected multicomponent water treatment approaches founded on the management of biomass entirely or when merged with other nonbiological substances. The associated results disclosed that this mutual approach augmented the elimination of EPs from wastewaters. This was the case for membrane bioreactors (membrane filtration/microbial degradation) or collective adsorption/biodegradation, which illustrated fascinating cleansing potentials towards pharmaceuticals, pesticides, toxic polychlorinated compounds and varying contaminants of mounting concern. Generally, this technique is in the budding stage as major detailed research studies are executed in research facilities only and chiefly bounded to distinct constituent pollution in aqueous solutions. Scarcely any major investigations have been conducted with actual wastewater or other multifaceted real-case set-ups via these resources to minimize contaminants in wastewaters. Therefore, these biomass-based remediation techniques for EPs need to be attested in outsized pilot-scale systems.

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