INCREASING THE EFFICIENCY FOR REMOVAL OF EMERGING CONTAMINANTS FROM WATER: A REVIEW

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Abstract - *The presence of emerging contaminants in water sources poses a significant challenge to public health and environmental sustainability. These contaminants, ranging from pharmaceuticals and personal care products to industrial chemicals, have raised concerns due to their persistence, potential toxicity, and adverse effects on ecosystems. Consequently, there is a growing demand for effective removal strategies to mitigate their impact. This review paper explores recent advancements in techniques aimed at enhancing the efficiency of emerging contaminant removal from water. It provides a comprehensive analysis of various treatment methods, including physical, chemical, and biological approaches, highlighting their mechanisms, advantages, and limitations. Furthermore, emerging technologies such as advanced oxidation processes, nanotechnology-based treatments, and hybrid systems are critically evaluated for their potential to address the challenges associated with emerging contaminants. Additionally, the paper discusses the importance of optimizing operating conditions, considering factors such as pH, temperature, and reaction time, to maximize treatment efficiency. Furthermore, the review examines the role of emerging materials and adsorbents in enhancing contaminant removal, emphasizing their adsorption capacity and regeneration potential. Moreover, the paper addresses challenges related to the scale-up and implementation of treatment technologies, emphasizing the need for cost-effectiveness and sustainability. Overall, this review provides valuable insights into the current state of the art in emerging contaminant removal from water and identifies promising avenues for future research and development in this critical field.*

***Key Words*:** Emerging contaminants, Water treatment, Removal efficiency, Advanced oxidation processes, Nanotechnology, Adsorption, Biological treatment.

1.HISTORY

The endeavor to augment the efficacy of eliminating emerging contaminants from water has undergone a progressive evolution, with its inception rooted in the latter portion of the 20th century. As scientific inquiry elucidated the prevalence of pharmaceuticals, personal care products, and industrial chemicals in water sources, it became evident that conventional water treatment methodologies were inadequate in mitigating these emerging contaminants. The latter decades of the 20th century and the initial years of the 21st century bore witness to a surge in research and development endeavors, precipitating the emergence of advanced treatment modalities. Notably, advanced oxidation processes (AOPs) and membrane filtration technologies assumed pivotal roles in this trajectory. AOPs, harnessing the reactivity of hydroxyl radicals, ushered in a breakthrough by efficaciously degrading a broad spectrum of organic pollutants. Concurrently, membrane filtration technologies underwent substantial enhancements, affording heightened removal efficiencies for contaminants. The integration of nanotechnology further augmented adsorption processes, yielding proficient nanomaterial-based adsorbents. The adoption of these technologies was propelled by both regulatory imperatives and the industry's dedication to safeguarding water integrity. Notwithstanding substantial strides, the journey persists, with ongoing research endeavors concentrating on optimization strategies, innovative treatment methodologies, and the amalgamation of diverse barriers to comprehensively tackle emerging contaminants in water. The concerted endeavors of scientists, engineers, and policymakers on a global scale underscore a steadfast commitment to preserving public health and environmental integrity as this journey unfolds.

2.INTRODUCTION

It is widely acknowledged that among the array of emerging contaminants, antibiotics represent a paramount concern, as their discharge into the environment can engender an elevated prevalence of antibiotic-resistant bacteria within ecological systems. Nevertheless, other emerging substances, particularly those of a polar nature such as acidic pharmaceuticals, acidic pesticides, and acidic metabolites of non-ionic surfactants, warrant significant attention. By virtue of their physico-chemical characteristics—namely, high water solubility and frequently limited degradability—these compounds possess the capacity to permeate through natural filtration processes and engineered treatment systems, thus posing a potential hazard to the integrity of drinking water supplies.

Various categories of emerging contaminants, notably surfactant byproducts, pharmaceuticals and personal care products (PPCPs), and polar pesticides, have been observed to exhibit relatively modest elimination rates, with detections recorded in both wastewater treatment plant (WWTP) effluents and the adjacent surface waters. Nonetheless, comprehensive data pertaining to the occurrence, risk assessment, and ecotoxicological impacts of most emerging contaminants remain scarce, rendering the prognosis of their fate within aquatic ecosystems challenging. This scarcity can be attributed in part to the dearth of analytical techniques capable of discerning these compounds at trace concentrations. Indeed, the analysis of emerging contaminants presents a substantial analytical hurdle, owing not only to the diverse chemical properties exhibited by these substances but also to their typically minuscule concentrations (typically in the realm of parts per billion or parts per trillion) and the intricacies of the matrices in which they are found.

3.ANALYSIS OF EMERGING CONTAMINANTS IN WASTEWATER

The analysis of emerging contaminants within wastewater necessitates a comprehensive approach encompassing several distinct phases. Initially, a systematic identification and prioritization of potential contaminants are undertaken based on their perceived risks and implications. Following this, meticulous sampling and monitoring protocols are established to procure representative wastewater samples from diverse sources. Advanced analytical methodologies, including Liquid Chromatography-Mass Spectrometry (LC-MS) and Gas Chromatography-Mass Spectrometry (GC-MS), are subsequently deployed to ascertain the presence and quantify the concentrations of these contaminants with precision and accuracy. The resultant data gleaned from these analyses are subjected to rigorous scrutiny to elucidate occurrence trends, potential sources, and temporal variations of the identified contaminants. Concurrently, comprehensive risk assessments are conducted to evaluate the potential hazards posed by these contaminants to both human health and the surrounding environment. In tandem, various treatment strategies are explored and assessed for their efficacy in attenuating the presence of emerging contaminants within wastewater streams.

Central to this endeavor is sustained collaboration with regulatory bodies and agencies to inform the development of robust policy frameworks and regulatory measures. Furthermore, initiatives aimed at fostering public awareness and engagement are deemed indispensable for elucidating stakeholders about the critical importance of managing emerging contaminants within wastewater systems, thereby safeguarding the integrity of water resources and ensuring the preservation of public health.

4.CONTAMINANTS IN THE WASTE WATER

The composition of wastewater can vary significantly depending on its origin and the environmental context. Among the myriad of substances encountered in wastewater, some prevalent contaminants include:

4.1.Pathogens

These are disease-causing microorganisms such as bacteria, viruses, and parasites. They can pose serious health risks if wastewater is not properly treated before discharge.

4.2.Organic Matter

Wastewater comprises organic compounds, including proteins, carbohydrates, and fats originating from human waste, food waste, and various other sources. Inadequate treatment of these compounds can induce oxygen depletion in aquatic environments, thereby precipitating adverse repercussions on aquatic ecosystems and their inhabitants.

4.3.Nutrients

Wastewater often contains nutrients like nitrogen and phosphorus, which are essential for plant growth. However, excessive amounts of these nutrients can lead to eutrophication, causing algal blooms and disrupting aquatic ecosystems.

4.4.Heavy Metals

Industrial wastewater may contain heavy metals such as lead, mercury, cadmium, and chromium, which are toxic to humans and aquatic life even at low concentrations. These metals can accumulate in the environment and pose long-term risks to ecosystems and human health.

4.5.Chemical Pollutants

Various chemicals from industrial processes, household products, and agricultural runoff can end up in wastewater. These include pesticides, pharmaceuticals, detergents, solvents, and other synthetic compounds, which can have harmful effects on both human health and the environment.

4.6.Suspended Solids

Wastewater frequently encompasses suspended solids such as sediment, soil particles, and other forms of particulate matter. Without appropriate management, these constituents have the potential to obscure water clarity, impede the functionality of water treatment infrastructure, and detrimentally affect aquatic ecosystems by smothering habitats.

4.7.Oil and Grease

Wastewater from industrial activities or urban runoff may contain oils, greases, and other hydrocarbons. These can form surface slicks, coat aquatic organisms, and degrade water quality if released untreated.

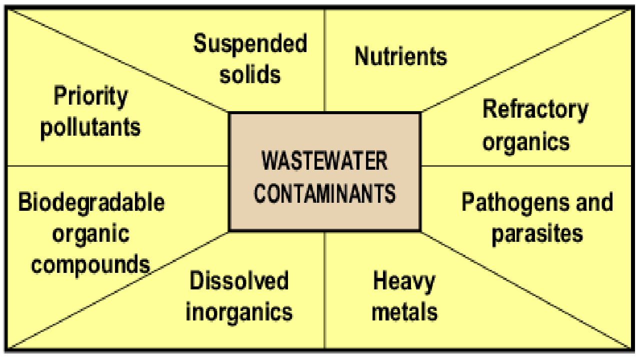

Figure-01: Contaminants in the waste water

5.REMOVAL OF EMERGING CONTAMINANTS FROM WASTE WATER

There are several methods used for the removal of emerging contaminants from wastewater, which include:

5.1.Activated Carbon Adsorption

Activated carbon is highly effective in adsorbing a wide range of organic contaminants from wastewater due to its high surface area and adsorptive capacity.

5.2.Advanced Oxidation Processes (AOPs)

AOPs such as ozonation, UV/H2O2, and photocatalysis (e.g., using titanium dioxide) generate highly reactive hydroxyl radicals that can degrade organic contaminants into harmless byproducts.

5.3.Membrane Filtration

Techniques such as reverse osmosis (RO), nanofiltration (NF), and ultrafiltration (UF) can effectively remove contaminants by physical separation based on size and molecular weight.

5.4.Biological Treatment

Processes like activated sludge, biofiltration, and constructed wetlands utilize microorganisms to degrade organic pollutants through biological activity.

5.5.Chemical Precipitation

Addition of chemicals such as coagulants (e.g., alum, ferric chloride) can facilitate the precipitation of contaminants for subsequent removal.

5.6.Ion Exchange

Ion exchange resins can remove contaminants by exchanging ions in the wastewater with ions on the resin surface.

5.7.Electrochemical Treatment

Techniques like electrocoagulation, electrooxidation, and electrochemical advanced oxidation processes (EAOPs) can effectively degrade contaminants by applying an electric current.

5.8.Hybrid Processes

Combining multiple treatment methods (e.g., membrane bioreactors, AOPs followed by membrane filtration) can enhance removal efficiency and treat a wider range of contaminants.

5.9.Phytoremediation

Using plants to uptake, accumulate, or degrade contaminants present in wastewater.

5.10.Adsorbent Materials

Besides activated carbon, various other adsorbent materials such as graphene oxide, metal-organic frameworks (MOFs), and biochar are being investigated for their effectiveness in removing emerging contaminants.

6.LITERATURE SURVEY

In this section of the literature review, we have studied the previous (past) research work based on the removal of the contaminants in the waste water, and summary of the all previous research work is given below:

Honglan et.al (2012): Although emerging contaminant compounds are typically present in waters at trace concentrations, their potential adverse effects on aquatic organisms, wildlife, and human health should not be underestimated, given their continuous release into water systems. The assessment and removal of emerging contaminants and their transformation products present formidable challenges due to the intricate nature of contaminants within water samples. Nonetheless, considerable strides have been achieved in assessing numerous emerging contaminants, owing to the dedicated efforts of scientists across various research domains. Future trends in the assessment and removal of emerging water contaminants are expected to focus on the oxidation/degradation products and metabolites of emerging contaminants, as their comprehensive documentation remains incomplete. Leveraging advanced analytical techniques enables the identification and quantification of these contaminants, thereby enhancing understanding of their occurrence, formation, properties, and pathways. The development of viable techniques for the removal of these contaminants, encompassing precursors, degradates, and disinfection byproducts (DBPs), is poised to emerge as a principal priority in the coming years. Establishing effective methodologies for their removal or mitigation below regulated thresholds is imperative to safeguard water quality and public health.

Djamel , Noureddine (2019): Integrated systems, such as Membrane Bioreactors (MBR) coupled with Reverse Osmosis (RO), Nanofiltration (NF), or Ultrafiltration (UF), exhibit enhanced efficacy in the removal of Endocrine Disrupting Compounds (EDCs) and pharmaceuticals, albeit demonstrating lower performance in pesticide reduction. Ozonation combined with a biological activated carbon hybrid system has demonstrated efficiency in reducing pesticides, beta-blockers, and pharmaceuticals. Similarly, ozonation integrated with ultrasound systems has shown the potential to eliminate up to 100% of certain pharmaceuticals, including salicylic acid, ibuprofen, naproxen, acetaminophen, cocaethylene, benzoylecgonine, enalapril, nor-benzoylecgonine, ketoprofen, atorvastatin, bezafibrate, clindamycin, sulfamethazine, and 4-aminoantipyrine. Hybrid systems incorporating activated sludge coupled with UF or activated sludge combined with gamma radiation have demonstrated cost-effectiveness in eliminating various EDCs, pesticides, and analgesic pharmaceuticals. Combined setups employing ultrafiltration and activated carbon, followed by ultrasound processing, present a promising technology for addressing a wide range of Emerging Contaminants (ECs); however, their cost-effectiveness may vary.

Bwapwa, Jaiyeola (2019): The presence of contaminants in both drinking water and wastewater poses multifaceted risks to the environment, spanning developmental, growth, and reproductive impacts. Identifying the causal factors behind these effects is imperative. Implementing optimal strategies is paramount to mitigating adverse environmental consequences associated with contaminants in drinking water and wastewater. Thus, interventions aimed at elucidating contamination sources and addressing associated challenges are strongly advocated to uphold environmental safety and sustainability. The current efficacy of removing the aforementioned "emerging contaminants" from wastewater and treating drinking water is not as satisfactory as desired. Enhancing treatment processes and ensuring stringent control thereof are crucial to maximizing the elimination of such micropollutants. Utilization of readily available absorbents for wastewater treatment containing pollutants is commonplace. However, achieving optimal pollutant removal depends largely on selecting the most suitable adsorbents, which poses a primary challenge. The effectiveness of treatment hinges on various factors, including not only the adsorbent and adsorbate characteristics but also environmental conditions and several operational variables pertinent to the adsorption process. Examples of such variables encompass pH, ionic strength, temperature, presence of competing organic or inorganic species in the solution, prior adsorbate exposure, adsorbent concentration, contact time, agitation rate, and particle size distribution.

Riya, Kanmani (2020): Certain Emerging Contaminants (ECs) have been consistently identified as prevalent and widespread. Among them are carbamazepine, sulfamethoxazole, caffeine, triclosan, triclocarban, perchlorate, sucralose, and organochlorine pesticides. Elevated levels of antibiotics, Active Pharmaceutical Ingredients (API), and Antibiotic Resistance Genes (ARG) have been detected in regions proximate to major pharmaceutical manufacturing centers such as Hyderabad. Numerous studies have documented the presence of ECs in various water sources, including surface water, groundwater, drinking water, as well as in treated wastewater from Sewage Treatment Plants (STP) and Common Effluent Treatment Plants (CETP). Endocrine Disrupting Compounds (EDCs), such as plasticizers, Polychlorinated Biphenyls (PCBs), and steroid hormones, have also been identified in water samples, with Di(2-ethylhexyl) phthalate (DEHP) emerging as a commonly observed phthalate compound. ECs have the potential to induce harmful effects on aquatic and terrestrial wildlife, vegetation, and human populations, persisting in the environment, bioaccumulating, and exerting toxicological impacts. Biological treatment and adsorption techniques have demonstrated limited efficacy in removing ECs, prompting exploration of advanced oxidation processes utilizing visible light-driven photocatalytic ozonation, which has shown high effectiveness in removing most ECs, with the exception of Perfluorinated Compounds (PFCs), which are more efficiently removed through electrochemical methods. Consequently, the review underscores the importance of integrating Advanced Oxidation Processes (AOPs) into STPs, CETPs, and Water Treatment Plants (WTPs) to enhance the removal of ECs from water sources.

Lopez et.al (2021): A comprehensive investigation was conducted to assess the impact of a Wastewater Treatment Plant (WWTP) on the Manzanares River in Madrid, Spain. The study focused on 40 Pharmaceutical and Personal Care Products (PhACs) and 7 pesticides listed in the EU Watch List (2018). The findings revealed a notable enhancement in WWTP removal efficiency following the implementation of tertiary advanced treatment measures, which included microfiltration using textile mesh, advanced oxidation treatment employing ozone generators, and ultraviolet (UV) disinfection. The influence of wastewater effluents on the Manzanares River was discernible through elevated concentrations of pharmaceuticals and pesticides, as well as an increased number of detected compounds downstream of the WWTP discharge point. Specifically, only two pharmaceuticals (gabapentin and iopromide) exceeded 500 ng/L, while six others (clarithromycin, irbesartan, salicylic acid, tramadol, valsartan, and venlafaxine) surpassed the threshold of 100 ng/L. Regarding pesticides, only imidacloprid and acetamiprid were detected in samples collected downstream of the discharge.

Nadia et.al (2021): Research in the field of biological technologies aimed at the degradation of emerging contaminants and mitigation of their environmental impact is currently experiencing significant development, with substantial advancements anticipated in the future. Biological approaches encompass a variety of techniques, including constructed wetlands, biomembrane reactors, strategies utilizing algae, fungi, and bacteria, as well as enzymatic degradation. While membrane filtration is already utilized as a tertiary treatment method capable of effectively removing a broad spectrum of pollutants and pathogens from water, its widespread adoption is hindered by its high cost and issues related to membrane clogging. Advanced oxidation processes stand out as particularly promising strategies due to their efficiency and simplicity, with the potential for integration into wastewater treatment plants at various stages (primary, secondary, and tertiary). Despite the anticipated progress in this area, considerations pertaining to investment, operational requirements, and maintenance costs remain pivotal. Convincing industrial stakeholders to incorporate these technologies into municipal wastewater treatment facilities will be essential moving forward.

Lichtfouse et.al (2022): Materials such as cyclodextrin polymers, metal-organic frameworks, molecularly imprinted polymers, chitosan-based materials, and nanocelluloses exhibit significant potential in environmental applications; however, they are currently in the laboratory study phase. Further research is imperative to elucidate the methods for integrating these adsorbents into full-scale treatment plants. Among the various disinfection methods, chlorination and ozonation demonstrate promising results in terms of effectively removing both pathogens and emerging contaminants. Nevertheless, additional investigations are necessary to assess the potential toxic characteristics of disinfection by-products in comparison to their parent compounds, as well as to discern the potential synergistic adverse effects of by-product mixtures even at trace concentrations.

Anupama et.al (2022): Relying solely on a single treatment advancement may not be the optimal approach for effectively removing Emerging Contaminants from water. It is essential to explore the use of coupled systems that can address the limitations inherent in individual innovations for removing these complex contaminants from the aquatic environment. Scaling-up studies focusing on natural processes often lack identification of the microorganisms responsible for removing Emerging Contaminants, instead only indicating their utilization as activated sludge capable of eliminating contaminants. Furthermore, while such processes have demonstrated efficiency in treatment, scaling-up studies often do not include exploratory development or detailed characterization of the various processes investigated.

Ishfaq et.al (2022): There remains a significant dearth of understanding regarding the fate of Emerging Pollutants (EPs) throughout wastewater treatment processes and their subsequent impact within ecosystems. Concerns have been raised regarding the accurate detection of EPs by treatment facilities, attributed to limitations inherent in commonly utilized sampling techniques. Therefore, the re-evaluation of the removal efficiency of different treatment processes under various operational conditions, facilitated by improved sampling methodologies, is imperative. Such re-evaluation will inform the implementation of appropriate measures to address EP proliferation. The ongoing trend towards the adoption of strategies aimed at reducing energy consumption in wastewater management is expected to foster the utilization of innovative treatment methodologies. Algae ponds, for instance, present a promising avenue for secondary effluent treatment, offering the potential for indirect energy generation through biogas processing. However, there is a paucity of reports documenting the success of algae ponds in EP elimination, underscoring the need for further research in this domain.

To elucidate the fate and elimination of EPs throughout treatment processes, comprehensive studies of such processing steps are necessary, considering their practical application in traditional treatment protocols. A holistic approach must also extend to environmental monitoring, encompassing the assessment of EP destiny and impact across terrestrial environments throughout their entire life cycle. This involves quantifying EP presence in biosolids and amended soils, alongside conducting research to understand their behavior. Comprehensive investigations of transformed soils under environmental conditions are essential to analyze phenomena such as leaching, drainage, effects on surface water quality, soil degradation, toxicity to terrestrial species, and potential absorption by plants, thus integrating into the food web. Similar methodologies may be employed for tracking EPs in other polluted environmental compartments, such as river sediments. The integrated use of biochemical assessment tools will enable a more thorough evaluation of the environmental risks posed by EPs, thereby facilitating the development of detailed environmental risk assessments.

Cristina et.al(2023): The challenge associated with this material lies in reducing its costs, exploring alternative materials for its production, employing environmentally friendlier substances for activation/regeneration, and maintaining its adsorption efficiency post-regeneration. Nanomaterials also show promise as an alternative for removing Emerging Contaminants (ECs); however, scaling up production and improving their separation from the aqueous medium are necessary. Industrial waste and agro-industrial residues, such as rice husks, coconut fibers, corn cobs, peanut shells, sugarcane bagasse, and fruit shells/seeds, present promising alternatives to replace activated carbon. These materials offer low to zero cost, high availability, and relatively high adsorption capacities (up to 300 mg/g). Furthermore, utilizing agro-industrial waste for this purpose not only addresses waste management issues but also aligns with the principles of the circular economy and sustainable development goals. Additionally, due to the low toxicity of agro-industrial residues, they can be utilized alone or in combination in biofiltration technologies.

Xiaohu et.al (2023): With the continual advancement in research and practical implementation, treatment technologies for emerging contaminants have progressively evolved and matured. Carbon-based adsorption technology, membrane separation technology, advanced oxidation methods, and constructed wetlands have demonstrated efficacy in removing emerging contaminants from water; however, they also exhibit inherent limitations and application constraints. Among these approaches, photocatalytic technology stands out as a promising solution due to its high efficiency and minimal secondary pollution. Immobilization plays a crucial role in the application of photocatalytic technology. Various immobilization methods have been explored through experiments and practical applications. Nonetheless, to further enhance the application of photocatalytic technology, there is an urgent need for more extensive research on existing immobilization methods. Specifically, it is recommended to conduct comprehensive small-scale and pilot-scale experimental studies and application research on real water bodies to advance the field.

7.CONCLUSION

In conclusion, the comprehensive review presented herein underscores the pressing need for enhanced methodologies to address the removal of emerging contaminants from water sources. Through a meticulous examination of existing literature, it becomes evident that while various technologies exhibit promising capabilities, there remains significant room for advancement to achieve optimal efficiency and efficacy. The multifaceted nature of emerging contaminants necessitates a multidisciplinary approach, integrating advancements in materials science, chemistry, engineering, and environmental science. Furthermore, the identification of novel treatment strategies and the refinement of existing techniques underscore the importance of ongoing research and innovation in this field. Collaborative efforts between academia, industry, and governmental agencies are imperative to catalyze the translation of research findings into practical solutions for water treatment infrastructure worldwide. Ultimately, the pursuit of increased efficiency in the removal of emerging contaminants from water is integral not only for safeguarding public health and environmental integrity but also for fostering sustainable water management practices for generations to come.

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