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Recent Advances in the Process of Removal of Emerging Pollutants from Wastewater: A Review

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Abstract

Both natural and artificial materials that have recently been discovered to be present in wastewater and adversely affect aquatic life and human health are referred to as emerging contaminants. Pharmaceuticals, antibiotics, hormones, artificial colors, flame retardants, and other emerging contaminants are released into the environment either directly or indirectly from hospitals, farms, factories, and other sources. Techniques have been created to help polluted water treatment technicians get over their obstacles. Physical, chemical, and biological advanced treatment technologies have been researched for the removal of emerging contaminants and for lowering the levels of effluents in water that is discharged. Numerous methods have been studied, including membrane filtration, adsorption, coagulation-flocculation, solvent extraction, ion exchange, photodegradation, catalytic oxidation, electrochemical oxidation, ozonation, and precipitation. According to earlier studies, these methods effectively eliminate one or more pollutants from wastewater, but they fall short in effectively eliminating the majority of harmful chemicals. Technologies that utilize nanomaterials could be an effective way to remove various toxins from wastewater. Due to their high energy consumption while treating wastewater for large-scale reuse, these systems are expensive. Therefore, in order to achieve full and improved emerging contaminants removal by wastewater treatment plants, further study is needed to improve wastewater treatment processes.

Keywords: wastewater treatment, membrane filtration, effluents, emerging contaminants, nanotechnology, adsorption, pharmaceuticals, aquatic environment

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1. Introduction

Wastewater is referred to as water that contains unwanted materials, such as dispersed or dissolved solid particles, organic and inorganic materials, or other contaminants that significantly affect its quality and make it unfit for use [1]. The primary sources of wastewater production, such as industry, residential and commercial regions, agricultural sources, etc., have a significant impact on the wastewater's content [2]. The risk of drinking tainted water and associated problems with sanitation are growing daily in developing countries. Water makes up almost 70% of the earth's shells and is necessary for survival of all living things as well as a number of manufacturing sectors. Fresh water makes up around 3% of the earth's total water supply, of which 0.01% is usable by humans. Water shortage is caused by the direct release of untreated pollutants into groundwater from a variety of businesses, which prevents the ecosystem's ability to use water efficiently. One of the biggest concerns for mankind and sustainable growth is water scarcity [3]. The growing global population has resulted in acute water scarcity for approximately 1.2 billion people, and 1.8 billion people are expected to experience water inadequacy in the future, according to a UNO report. Water pollution is a bigger hazard to aquatic life, human health, and the environment than water shortages. Water characteristics are significantly impacted by a number of newly discovered substances in drinking, ground, and surface water. Water is a universal solvent, but when harmful compounds dissolve in it, quality of water is impacted, leading to water pollution [4].

The need for water is growing as a result of industrialization, population growth, atmospheric adaptability, and environmental obliteration [5]. One of the biggest obstacles to recycling water sources is the presence of both organic and inorganic contaminants in wastewater. The most recent current treatment methods are still limited in their ability to detect trace levels of undetermined pollutants in the assessment of developing contaminants [6]. Numerous analytical techniques have been created recently for different emerging pollutant types. Before industrial effluent is released into the aquatic environment, it becomes crucial to separate these harmful substances from water. The creation of effective methods has been a key focus of environmental research for this reason. Conventional cleanup techniques generally divided into three categories: chemical, physical, and biological. Because synthetic dyes are resistant to aerobic biodegradation, biological therapy is straightforward and inexpensive, but it is ineffective for them. Physical treatment is typically more successful than chemical treatment, which is inefficient and produces harmful byproducts. Numerous methods, including membrane filtration, coagulation-flocculation, solvent extraction, ion exchange, catalytic oxidation, electrochemical oxidation, precipitation, etc., have been tested to remediate these organic contaminants found in water. The problem is made more difficult for the researchers by the fact that these methods are less efficient, very costly, and do not remove the pollutants from contaminated water. In addition to these methods, adsorption and photocatalytic degradation are thought to be the most promising strategies for eliminating pollutants from wastewater [7].

2. Emerging pollutants

Water quality is significantly affected by emerging contaminants, also known as contaminants of emerging concern, emerging pollutants, micro-pollutants, or trace organic compounds, which come from a variety of natural and man-made sources [8]. They are frequently referred to be emerging not because they are recently discovered but rather because the level of concern has increased. In the atmosphere, these pollutants are often found in trace amounts, ranging from nano-grams per liter to micrograms per liter. According to the United States Environmental Protection Agency, emerging contaminants are novel chemical compounds that may have detrimental impacts on both human health and the environment [9]. To meet water demands, wastewater must be treated and recycled to a suitable standard (Figure 1).

2.1. Classification of Emerging Pollutants

Pesticides, pharmaceuticals, artificial organic dyes, polycyclic aromatic chemicals, heavy metal ions, adhesives, per-fluorinated compounds, flame retardants, surfactants, and other substances produced by human activities in the home, healthcare facilities, agriculture, and industry are examples of emerging contaminants. Chronic toxicity results from their presence in trace amounts (Figure 2).

2.1.1. Pesticides

Pesticides are a group of organic pollutants that fall into many categories according to their chemical and physical characteristics. Pesticides can accumulate in humans and plants and are often found in groundwater, causing toxicity depending on where they are applied. Compared to other compounds, dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane are most frequently used pesticides (about 67%) among the pesticide contaminants [10].

2.1.2. Pharmaceuticals Industry

Pharmaceuticals are a substantial novel organic pollutant that is found in trace concentrations in water supplies all around world [11]. Pharmaceuticals are widely utilized in veterinary and human healthcare on a regular basis for purposes like prevention, therapy, nourishment, and investigative aids. Antibiotics like diclofenac, steroids, antidepressants, beta blockers, analgesics, salicylic acid, anti-inflammatory medications, tranquilizers, lipid-lowering medications, and stimulants, etc. are among the medications frequently found in wastewater [12]. Hormones, both organic and inorganic, can enter the atmosphere through farming, are not entirely removed from wastewater, and endanger both humans and aquatic life.

2.1.3. Personal Care Products

Personal care products are popular household chemicals used for hygiene, scent control, cosmetics, and well-being. Personal care goods such as lotions, sunscreens, soaps, hair and facial care products, and decorative cosmetics contain these compounds. Due to the widespread usage of personal care products the amount of these pollutants released into the environment is rising daily [13]. Cosmetics are the most often used of these compounds, therefore their presence in the air in little amounts could harm people, animals, and the environment.

2.1.4. Surfactants

Surfactants are synthetic organic chemicals that are hazardous to aquatic organisms and are utilized worldwide in the production of personal care products, detergents, paints, emulsifiers, and insecticides [14]. They fall into one of three categories: cationic, anionic, or zwitterionic surfactants. Even at low quantities, commonly used surfactants like octylphenol and nonylphenol ethoxylates are extremely hazardous.

2.1.5. Food Additives

Many artificial sweeteners, including sucralose, saccharin, and acesulfame, which are widely used in food, medicine, and personal hygiene items, end up in household wastewater through human excretion. These moderately digested sweeteners pose a danger to aquatic systems (plants, algae, and fish) and are typically difficult to remove from the environment [15].

2.1.6. Flame Retardants

Toxicity results from wastewater treatment plants releasing flame-retardant substances into the contaminated sea surface water. Because they are hydrophobic, polybrominated diphenyl ethers are mostly utilized as flame retardants in the production of electronic cables, computers, carpets, and polyurethane foams [16].

2.1.7. Microplastics

Microplastics are becoming the largest cause of pollution called as the white pollution. In Asia a lot of goods being sold contain plastic in any form and thus cause pollution while almost 32.0% of pollution in China is caused by presence of plastic in materials. Plastic pollution in water is making life difficult for species both on land and in water. Microplastics are generally produced from processes like primary processes such as production of beauty products, microfibers and microbeads and also through secondary processes such as mechanical weathering, friction, aberration and fragmentation of large-sized plastics [17].

2.2. Potential Sources of Emerging Pollutants

Sources of emerging contaminants are same as those of well-known contaminants, and they are discharged into environment by home, industrial, mining, agricultural, and medical facilities. These sources fall into two categories: non-point sources & point sources [18]. Point sources are released in high concentrations from a specific location. Non-point sources, known as diffused sources, disseminate pollutants from indistinguishable origins over wide areas in small amounts. Low amounts of various by-products released when medications and personal hygiene items used often. Their physical and chemical characteristics are impacted by their presence in water & environment. In marine environment, thousands of these emerging contaminants and their metabolites have been found to be more toxic and dangerous. In general, wastewater treatment facilities are not built with efficient removal of emerging toxins (Figure 3) [19].

2.3. Toxic Effects of Emerging Contaminants

Numerous reports of the harmful effects of recently discovered contaminants on living things demonstrate to the fact that even minute amounts of these pollutants can have detrimental consequences on both humans and animals, including chronic poisoning and endocrine disruption. Consuming foods and beverages linked to polluted soil, water, and microorganisms is the main way that humans come into contact with endocrine-disrupting chemicals, which causes biomagnification and bioaccumulation in the human body. Researchers are currently concentrating on emerging contaminants found in surface waters for a variety of reasons, including the fact that surface waters are easier to monitor than groundwater and frequently contain large quantities of a wide variety of contaminants, especially when they are directly linked to industrial discharges [19].

3. Traditional Treatment Methods for Wastewater

Physical, chemical, and biological methods are used in typical wastewater treatment to eliminate both soluble and insoluble contaminants. Manufactured contaminants like dyes are resistant to aerobic bio-degradation, biological therapy is simple, inexpensive, and ineffective. Physical treatment is typically more effective than chemical treatment, which is less effective and produces harmful byproducts. Wastewater treatment has several stages, including primary, secondary, tertiary, and preparatory (Table 1) [20].

3.1. Preliminary Techniques

Dead animals, papers, oils, grease, and other suspended debris are removed from wastewater with the use of preliminary treatment. Preliminary treatment uses a variety of components, including skimming reservoirs, accumulation and flotation tanks, and screening. While flotation units and skimming tanks remove oils and greases, the accumulation tank is used to collect sand and grain [21].

3.2. Primary Techniques

Floatation and sedimentation procedures are used as initial treatment to eliminate both organic and inorganic components. Unprocessed nitrogen, raw phosphorus, and heavy metals associated with suspended contaminants are drained out during this process. This technique lowers the levels of biochemical oxygen demand in wastewater by 5–40%, 50–70% of all floating particles, and up to 65% of oil and grease. Primary treatment is necessary in many developed nations in order to utilize wastewater irrigation for crops that are not used by humans [20].

3.3. Secondary Techniques

Organic effluent that bypasses basic treatment is removed by secondary, or biological treatments. Through oxidation or nitrification, this process changes organic stuff and turns it into a stable state. Filtration and activated sludge techniques are the two categories of this sewage treatment technique. This treatment uses a variety of filters, including cascading filters, contact beds, and uneven sand [22].

3.4. Tertiary Techniques

Tertiary treatment used to remove certain effluents that secondary methods are unable to fully eliminate. Approximately 99.01% of all pollutants removed throughout this process. Through this procedure, inorganic materials like phosphorus and nitrogen are eliminated, and wastewater quality is restored so that it can be used again for drinking and irrigation without endangering environment [22].

4. Available Techniques for Wastewater Treatment

Conventional wastewater treatment facilities are typically not built to remove new contaminants. Presence of ECs in environment causes cancers, neurotoxins, endocrine disruption, resistant microbes, and impacts marine life and public health. Numerous methods, including membrane filtration, coagulation-flocculation, solvent extraction, ion exchange, catalytic oxidation, electrochemical oxidation, precipitation, and others, have been tested to remove these organic contaminants from water. The problem is made more difficult for researchers by fact that these methods are less efficient, very costly, do not totally remove pollutants from contaminated water. In addition to these methods, adsorption and photocatalytic degradation thought to be viable strategies for eliminating pollutants from wastewater (Figure 4) [23].

4.1. Membrane Filtration

A physical technique used to remove emerging pollutants from aquatic systems is membrane technology. In order to eliminate suspended pollutants, membranes are made of materials with filtering characteristics including hydrophobicity, pore size, and a certain surface charge. Ultra-filtration, nano-filtration, microfiltration, forward osmosis, and reverse osmosis are the several types of membrane filtration. Although major membrane techniques can reduce emerging pollutants by more than 99%, they have not yet been implemented on a broad system [24]. Depending on the membrane and type of pollutant, the ultrafiltration method removes colloidal, suspended, or dissolved contaminants at low pressure. Its pore size ranges from 0.001 to 0.1 μm, making it easier for dissolved hydrated metal ions to flow through. Polymer enhanced ultrafiltration and Micellar enhanced ultrafiltration methods have been investigated to improve removal effectiveness of metal ions including copper, zinc, chromate, cadmium, nickel, and organics like phenol, etc. Microfiltration, is frequently used at atmospheric pressure and has pore sizes ranging from 0.1 to 10 μm, is unable to efficiently remove pollutants larger than 1 μm. Both forward and reverse osmosis use semi-permeable membranes & rely on osmotic pressure gradients. Depending on kind of membrane and contaminant, nanofiltration membranes have small pore sizes ranging from 1 to 10 nm and are highly effective at removing emerging pollutants. It can be used to eliminate both natural hormones and medicines, including progesterone, sulfonamide and fluoroquinolone antibiotics, and anti-inflammatory medications [25].

4.2. Coagulation-flocculation

Larger colloidal of dispersed dye-colored wastewater can be effectively removed using the coagulation-flocculation technique. In flocculation, aggregated flocs are united to form larger agglomerates that settle down due to gravity, whereas in coagulation, dye solution systems are dispersed to form flocs [26]. The textile industry frequently uses coagulation/flocculation, which is an affordable and straightforward method of purifying wastewater. Coagulants such as lime, ferric sulfate, aluminum sulfate, and ferric chloride mix with the contaminants in this approach and eliminate them through sorption or electrostatic interactions.

Figure 1: Different contaminants in wastewater

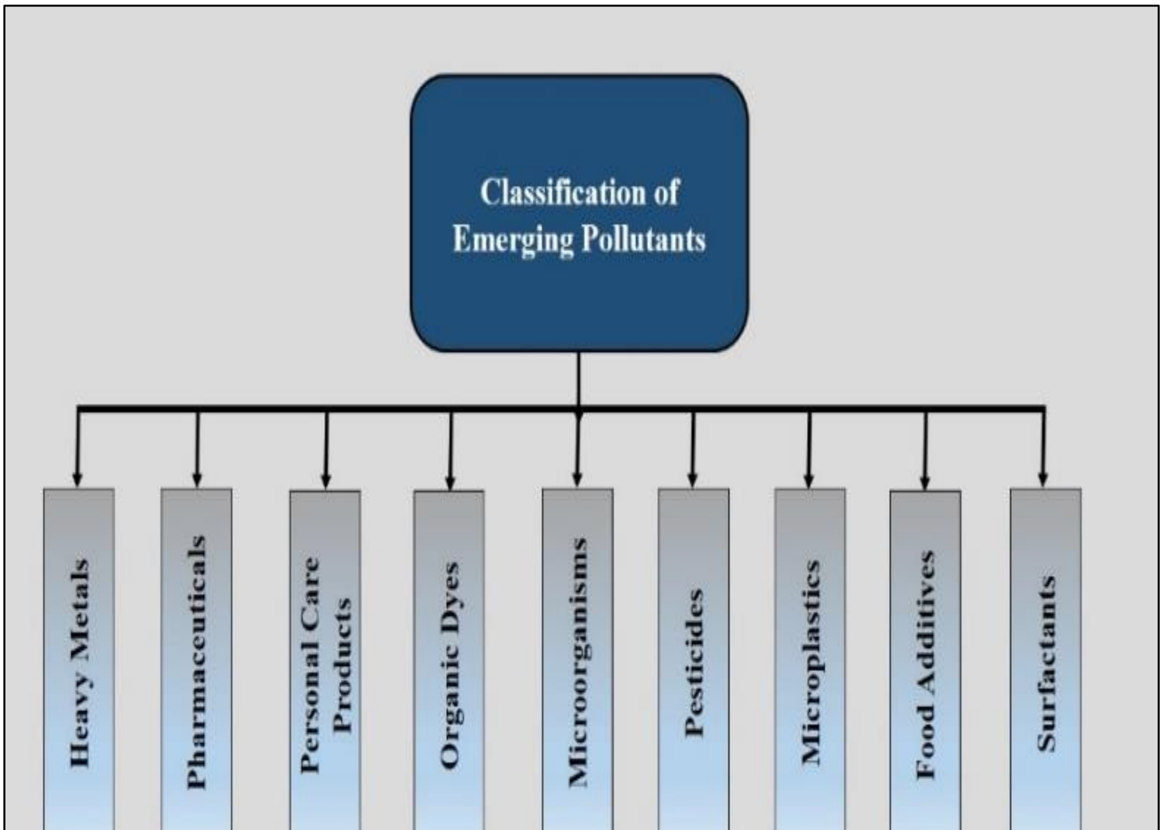

Figure 2: Classification of Emerging Pollutants

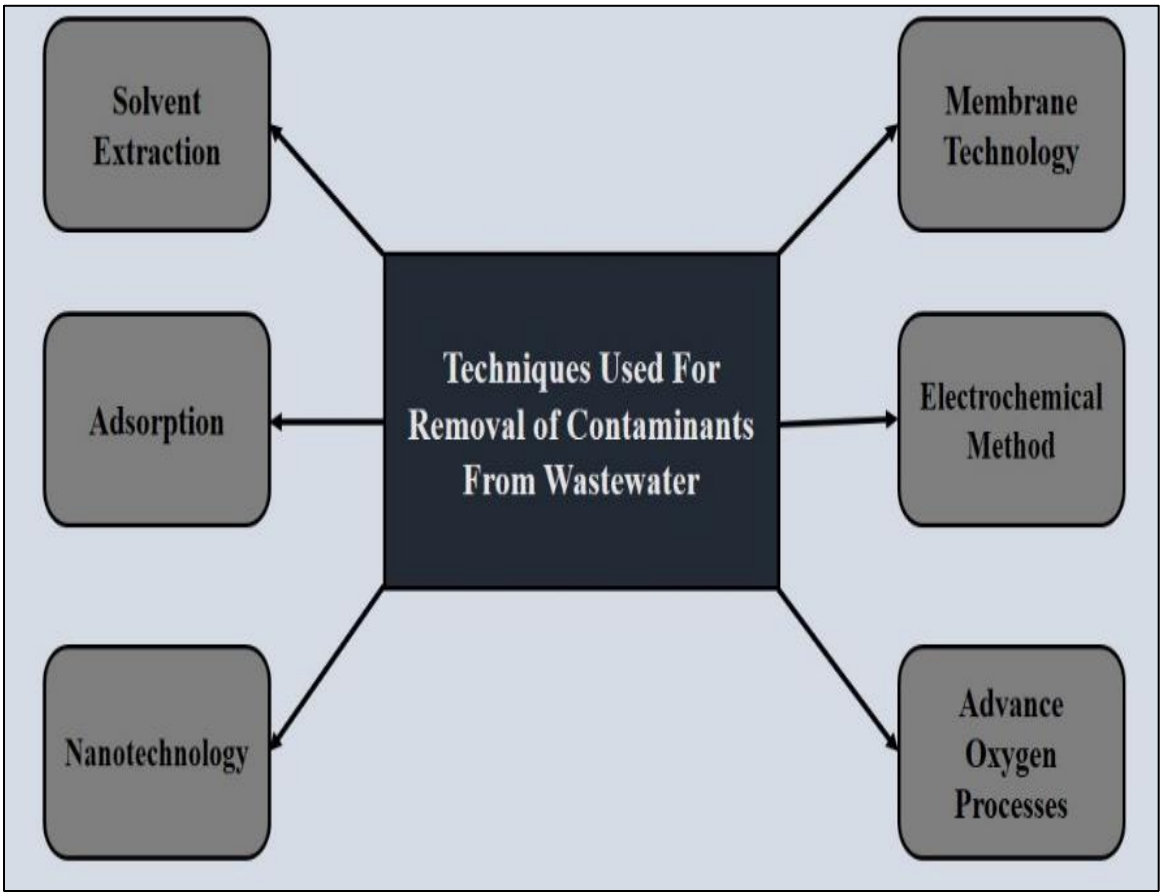

Figure 3: Sources of Emerging Contaminants

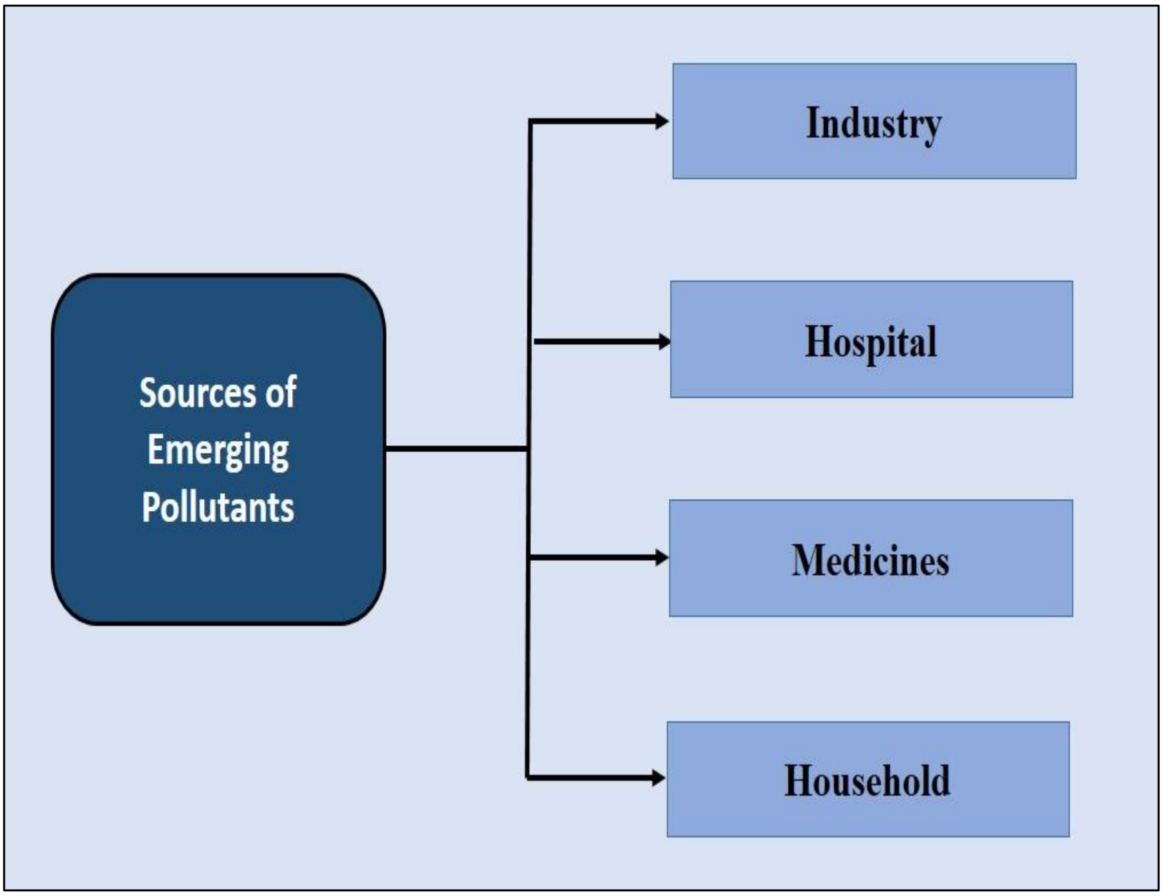

Figure 4: Methods Used for Wastewater Treatment

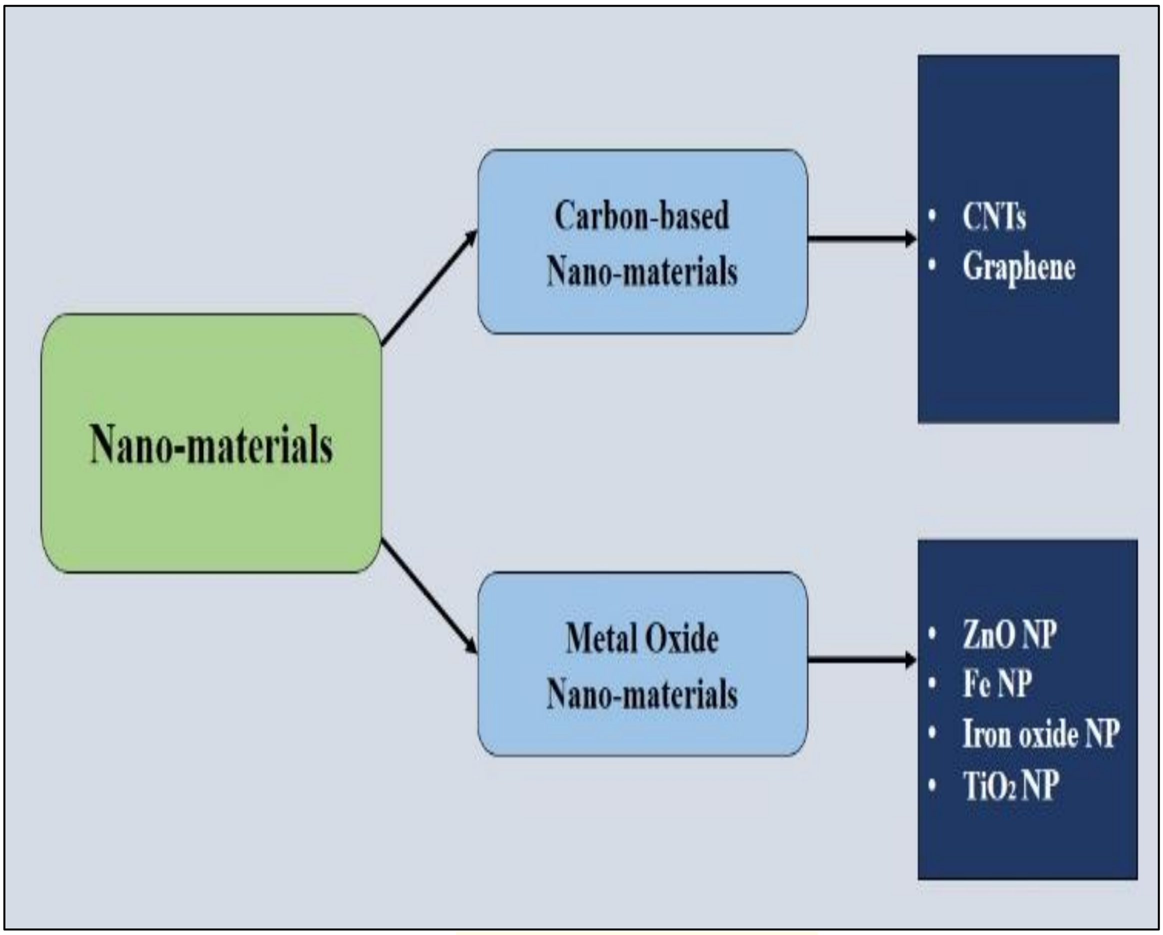

Figure 5: Different groups of nanomaterials

Table 1: Benefits and Challenges of Wastewater Treatment Methods [21]

Treatment	Basic methodologies	Benefits	Challenges
Screening	Solids smaller than 6 mm are eliminated using coarse screening. Elimination of impurities between 0.001 and 6 mm is done by fine screening.	Coarse screening reduces disruption and obstruction of the therapeutic technology. While, in fine screening efficiency is controlled by adjusting the screen openings' fineness. It is strongly advised to control the process's temperature. It is less costly.	Coarse screening is ineffective in eliminating the emerging contaminants while in fine screening, due to obstruction in the tiny holes, the screen needs to be cleaned. It is also a complicated procedure.
Adsorption	The method of using solid substrates with a very precise surface area to remove soluble compounds.	Easy to adopt, less complicated and costly, able to support other treatment procedures, and accurate and effective removal of emerging contaminants.	Unknown pollutants are challenging to remove since adsorbents are very selective and particular, and reverse osmosis needs energy.
Biosorption	The encapsulation of microorganisms on absorbents.	Highly efficient and specific treatment for removal of emerging contaminants.	Cleaning of absorbents is necessary at specific intervals.

There have been reports of using aluminum sulfate to remove medications including warfarin, bromazepam, and betaxolol through coagulation-flocculation. This method reduces wastewater's insoluble matter, soluble dyes, suspended particles, and coloring agents [27].

4.3. Solvent extraction

A popular method for removing organic and inorganic contaminants released into wastewater from different industries is solvent extraction. Three main operations serve as its foundation. The first step is to remove solute particles from water and transfer them to a solvent. The solute and solvent separation stage comes in second, while the solvent recovery stage comes in third. The main purpose of solvent extraction is to remove phenols, creosols, and other phenolic acids from contaminated water that contains trace amounts of solute from petroleum processing plants and coke-oven plants used in production of steel and plastics [28].

4.4. Adsorption

Adsorption is one of the most effective methods for treating wastewater because of its straightforward design, high level of expertise and convenience of use, low capital cost, simple recovery, adaptability, and technological viability without creating hazardous byproducts. This method's ability to remove and regenerate adsorbents has earned it recognition on a global scale. Both organic and inorganic pollutants from residential and commercial wastewater have been widely treated using this method [29]. To increase their adsorption efficiency, numerous studies have been conducted to find inexpensive adsorbents with high binding capacity and a large surface area. Because of its highly permeable surface area, favorable pore composition, and thermostability, activated carbon is frequently employed as a conventional adsorbent to remove colors and medicinal compounds from wastewater [30].

4.5. Advanced Oxidation Processes

In order to effectively treat wastewater, advanced oxidation processes have been created. In order to oxidize newly emerging pollutants, these methods rely on the production of hydroxyl or sulfate radicals. Occasionally, ozone and UV irradiation are employed for increased removal effectiveness. Instead of moving these substances to a different phase. These techniques effectively eliminate biologically harmful or non-biodegradable substances such insecticides, aromatics, petroleum constituents, and volatile organic compounds. Since OH^- is reduced to form H_2O as a byproduct, they can remove several organic pollutants simultaneously without creating any harmful substances in water [31].

4.6. Application of Nanotechnology

Nanomaterials are generally defined as materials having at least one dimension smaller than 100 nm. Their higher density and larger surface area result in increasing adsorption efficiency, surface reactivity, and resolution mobility. Current research in exploitation of nanomaterials has facilitated the application of nanotechnology in wastewater treatment through adsorption, advanced oxidation processes, and filtration. A variety of nanomaterials, including zerovalent metal nanoparticles, metal-oxide nanoparticles, carbon nanomaterials, and nanocomposites, have been reported for wastewater treatment (Figure 5) [32].

5. Future Perspective

It is very difficult for people to cope with newly discovered toxins in water sources. This calls for the use of extremely effective and affordable waste water management techniques as well as societal awareness. Wastewater treatment is currently a challenging task since it has a significant impact on the environment and life on earth. The best possible way to overcome difficulties in operational ignorance, ecological effect, efficiency, practicality, probability, and cost-efficiency has not been determined despite fact that variety of biological, physical, and chemical technologies for wastewater treatment have been researched to remove emerging pollutants. To achieve good water quality at a reasonable cost, two or more processes are combined for increased removal efficiency. Some possible further steps are necessary to tackle these challenges such as incorporating new concepts such as nano-technology and genetic engineering, Effective assessment of treatment to select most suitable treatment, applying green technologies on an industrial scale, and exploration of cross treatment systems is required for development of the appropriate model.

6. Conclusions

Toxic substances created by humans which are released into wastewater are known as emerging pollutants. The main causes of emerging contaminants include fertilizers, personal care items, and medicines. Both marine life and human health are negatively impacted by their existence. Conventional wastewater treatment techniques are unable to effectively remove them. Numerous treatment techniques have been discussed, including enhanced oxidation processes, membrane technology, coagulation-flocculation, solvent extraction, adsorption, and nanotechnology. There are benefits and also drawbacks to these methods. Hybrid systems have been found to be more effective in eliminating emerging pollutants but they have time, energy, and cost constraints. Using nanotechnology is a promising way to get around these restrictions. Therefore, in order to completely and effectively remove emerging contaminants from contaminated water, extensive research on wastewater treatment systems that are both technically and financially viable is needed.

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