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Emerging Contaminants in Water: A Review of Recent Research" on the occurrence, fate, and removal of emerging contaminants in water sources, highlighting recent developments in treatment technologies /A Review Article

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Abstract : Water is a prime commodity; however, it faces several challenges in its contamination by the emerging pollutants which include pharmaceuticals, industrial chemicals, and personal care products. These find their ways into the water either through sewage, agriculture, industrial discharge, or poor waste disposal. Most of these pollutants cannot be removed easily by the conventional methods due to their unstable nature. Some dispersal pathways involve biodegradation, chemical degradation, sedimentation, and evaporation. Advanced technologies like bioremediation, nanofiltration, and filtration techniques have come forward to deal with these pollutants. Understanding of these pollutants and their removal methods will help in improving the water quality and preserving the environment.

Key words: Emerging pollutants, treatment technologies, health risks

Introduction: Water gives life to Earth; however, it also comes with a number of challenges due to the contamination of the sources with emerging pollutants. Emerging pollutants can be defined as a class of chemicals whose environmental impact is either partly or fully uncharacterized, like pharmaceuticals, industrial chemicals, personal care products, plastic microbeads, and other undefined agents of hazardous effects to ecosystems and human health. These pollutants emitted into the water body have increased over these years due to their increased usage in everyday products through wastewater and agricultural runoff and industrial practices. Instability in the

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environment is one challenge along with many others that are faced, and removing these pollutants is not possible by conventional treatment techniques[2]. The present review covers the latest research on the occurrence and fate, and effective removal methodologies of emerging pollutants in water sources. It also discusses fresh developments on treatment technologies such as nanotechnology, bioremediation, and advanced analysis techniques that are helpful for assuring water quality and minimizing risks due to those pollutants. This review therefore covers the overview of the emerging pollutants, which hopefully may raise awareness and active response to the contemporary environmental challenges. Water Sources-Emerging Pollutants [3].

The emerging pollutants have developed special attention in the studies of water quality because of the complexities of these issues in the environment and their potential impact on public health and the environment. These pollutants refer to the varied chemicals that reach the environment through multiple means and routes that result in the contamination in one way or another. The details related to the occurrence of these varied pollutants are as follows according to [4]:

1.Sewage: Sewage has been determined to be the highest contributor to the entry of emerging pollutants into water bodies. When sewage is discharged without proper treatment, this water contains a wide variety of pollutants such as: pharmaceutical compounds. Many of the medicines remain in the water system upon use, like painkillers or antibiotics that can further act on living organisms and personal care products, include chemicals such as soap, shampoo, and perfumes, which are poisonous to aquatic life. Lack of adequate wastewater treatment causes seepage of the chemicals into the rivers and lakes, making surface water undrinkable.

2. Agriculture Application of pesticides and fertilizers: In agriculture is one of the most significant sources of emerging contaminants. The chemicals are leached through: Surface runoff: Rain or irrigation water can wash chemicals from fields into water bodies, and soil percolation include chemicals may leach into the groundwater, affecting the quality of well waters and other groundwater supplies, organic chemicals commonly include pesticides and nutrients such as nitrogen and phosphorus. These nutrients may stimulate excessive growth of aquatic plants, leading to eutrophication in water bodies.

3. Industrial discharge Industrial processes: also are one of the developing sources of water pollution. It involves the following : wastewater leakage, emitted from industries is irresponsibly drained into the water bodies, infusing contaminants into them, and toxic chemicals: These wastes are full of harmful chemicals, which include heavy metals - such as lead and mercury - along with industrial organic materials of those types that can cause detrimental effects on life, these act as contributors to the deteriorating quality of water and affect marine life, as well as human health.

4. Pharmaceutical waste: The improper disposal of medicines and personal care products is considered another important source of emerging pollutants. This occurs through the following,

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consumer disposal: Generally, the old or unused medicines enter toilets and sinks as their means of disposal into the system and hospital waste, the waste coming out of hospitals contains all types of medications and chemicals that can spill into water if not managed properly.
Various studies have pointed out that active pharmaceutical ingredients like antibiotics and psychotropic drugs were present in both surface and groundwater, which raise concerns regarding their effects on both aquatic life and human health.

Fate of Emerging Contaminants in Water :
The fate of the emerging pollutants, once they get into water sources, is chosen based on several main factors, such as the nature of the pollutant, concentration, surrounding environmental conditions, and chemical and biological interactions. The breakdown of the fate methods of these pollutants is given below according [5]:

1.Biodegradation: Biodegradation is one of the major natural mechanisms contributing to the removal of these pollutants from water. This includes: Microorganisms: Bacteria, fungi, and some algae can decompose organic pollutants; this helps to reduce the concentrations of organic pollutants in a given environment. The rate of microbial decomposition depends on the following factors according [6] :

a) Nature of the pollutant: Organic pollutants, such as drugs, degrade faster, but there is also a different type of pollutant, such as pesticides, which are not easily degradable by biological processes.

b) Environmental conditions: There are many environmental conditions related to temperature, pH, and nutrient requirements that microorganisms need in their own specific amounts.

2. Chemical Decomposition: The mechanism may be a reaction between the contaminant and any other substance that might be present in the environment to produce: By-product formation: Certain pollutants may react chemically with naturally occurring chemicals in water and form new compounds, that can be less or more toxic. Examples include: Medicines: Some medicines can combine chemically with chlorine or ozone in drinking water and produce toxic by-products, and agricultural chemicals: Such as pesticides, which can further degrade into new toxic compounds either by light or under harsh conditions[7].

3. Sedimentation: Sedimentation is the process where heavy pollutants settle down to the bottom of water bodies, leading to: Accumulation of pollutants: Some pollutants, such as heavy metals like lead and mercury, can be deposited in the beds of rivers and lakes. While sedimentation may be a means of removing such pollutants from the water, it may also concentrate these substances in the ecosystem to such an extent that the organisms which live on the bottom, such as fish and invertebrates, can be affected and re-introduction of contaminants:

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Sediments, through the action of environmental factors, such as water movements or human activities, may release their pollutants into the water again, thus affecting its quality[8].

4. Evaporation: Evaporation is one of the processes developing the dispersion of some pollutants in the environment, volatile chemical substances include organic solvents or some chemical pollutants that may evaporate and pass into the atmosphere. It spreads pollutants over wide areas to be accumulated again in certain new areas by unexpected pollution and atmospheric effects, these might precipitate with rainfall onto the surface or groundwater far from the source area[9].

The emerging pollutants are much resistant to their removal by conventional methods; hence, the removal of emerging pollutants from water sources requires sophisticated and complex technologies. In this section we go into detail on some of these advanced technologies being used in removing pollutants from water sources [10].

1. Biological treatment: Using microorganisms, this technology utilizes bacteria, fungi, and algae in the decomposition of organic pollutants in water. Such organisms convert harmful compounds to less toxic or harmless substances through respiration or fermentation. Effectiveness of biological treatment, this method has been able to treat some organic compounds such as medicines and pesticides effectively. However, this technology effectiveness depends on, type of pollutant: Some pollutants are more biodegradable than others. Environmental conditions: The microorganisms require optimum temperature, pH and nutrient availability amongst other factors to perform at their best[11].

2. Nanofiltration: Nanofilters: These filters at nano-size are installed to improve the effectiveness of the treatment process in removing contaminants from the water. These filters have features that involve the filtration of fine particles and small organic compounds include mechanism of action make use of surface effects and unique properties of nanoparticles for improved contaminant extraction. These filters can involve pressure filtration and high-pressure forcing of water through the filter and chemical reaction may improve absorption of contaminants via chemical reaction[12].

3. Chemical methods: Advanced oxidation: AOPs technologies operate by chemical catalysis, enabling contamination decomposition or removal. Such processes involve the use of oxygen, ozone, or other strong oxidizing compounds such as hydrogen peroxide. Efficiency of advanced oxidation: This process is very effective in removing complex organic pollutants such as pharmaceuticals and industrial chemicals. It was characterized to decomposition of contaminants: into simple compounds, that have the potential to be biodegradable or easily removed from water and toxicity reduction, it has an aim to reduce toxicity of the by-products produced from contaminants[13].

4. Advanced treatment techniques: **Reverse osmosis**: it is a technique used in separating contaminants from water through pressurizing of water across a partially permeable membrane.

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It used to remove salts as well as small organic materials[14].
UV: It applies in the water sterilization process, therefore killing microorganisms and organic pollutants. Its sterilization is very effective on certain water pollutants, especially viruses and bacteria[15].
Ion exchange treatment: The treatment technology depends on the exchange of ions between the wastewater and treatment for the removal of heavy metals among other kinds of pollutants[16].
Among the advanced technologies of water treatment, RO is considered one of the most effective means of removing pollutants from water. This principle involves the use of a semi-permeable membrane, which only allows water molecules to go through, but blocks the passage of pollutants and salts[14,17]. A special membrane is used that allows only water molecules to pass through while ions and all other impurities are not allowed to pass through. For the water seeping into the membrane, some amount of pressure is applied on it to push the water from the concentration side to the dilution side, while retaining all the impurities on the concentration side, which includes salts, heavy metals, and organic matter, thereby keeping pure water on the other side[18].
Some of the major benefits of reverse osmosis include its effectiveness in the removal of pollutants; reverse osmosis can remove as much as 99% salts and other impurities and improves water quality. Additionally, this technology raises the standard of water to levels it becomes fit for human consumption or agricultural application. The technology is also versatile since it can be applied in seawater, groundwater, and water polluted through industrial processes. Previous studies include assessment of the effect of reverse osmosis on the removal of salt talked about the performance of the reverse osmosis system in the removal of salts from seawater. It showed that more than 95% of salts can be removed by the process of reverse osmosis and that the resultant water is fit for human use.
Studying the application of reverse osmosis in industrial water treatment:
Other studies concerned the application of reverse osmosis to the treatment of industrial wastewaters. Tests showed that the technology removed heavy metals and organic pollutants from the wastewaters, decreasing pollution in the environment [19] .
Other studies were conducted with the purpose of comparing reverse osmosis to other technologies for the treatment of wastewater, including ultrafiltration and microfiltration. The results showed that reverse osmosis is the best technology among the three in removing small-sized pollutants [20].

There are a number of challenges that this technology is facing, including membrane leakage; as stated, there is a need to keep the semi-permeable membrane, which may cause some pollutants to leak out. Besides, there are also some costs, since the reverse osmosis will be expensive in terms of energy and maintenance costs. Regarding its environmental impact, the concentrated water discharge has a negative effect on the environment.
Reverse osmosis, therefore, can be considered an advanced and efficient technology involved in water treatment processes for the improvement of water quality and reduction of pollutant rates.

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Previous research evidences its effectiveness for various applications, hence upgrading its role to respond to fresh water and environmental pollutants challenges.
UV technology is one of the most effective methods in water sterilization, as it is used to kill microbes and organic pollutants. This technology relies on ultraviolet rays, which are part of the electromagnetic spectrum, and are characterized by their ability to weaken or destroy the DNA of microorganisms, which reduces their ability to reproduce. UV rays sterilize water by passing it through a specially designed system that emits UV rays. When microorganisms (such as bacteria and viruses) are exposed to the rays, their DNA molecules are exposed to them. This leads to a change in the genetic makeup of the microorganisms, which prevents them from reproducing and causes their death.
Effectiveness of UV rays: UV rays are very effective in killing many types of bacteria, including E. coli and salmonella and viruses, as UV rays can kill viruses that cause diseases, such as HIV and hepatitis virus[15,21]

In addition to killing microbes, UV also helps break down some organic pollutants in water, such as industrial chemicals and pharmaceuticals. One of the benefits of using UV technology is that it is highly effective, as it can kill up to 99.99% of microorganisms in water. And without adding chemicals, this technology does not require the addition of any chemicals, making it an environmentally friendly option. It is therefore tasteless and odorless, making it ideal for use in treating drinking water.
There are several challenges to using UV technology, such as the surrounding conditions, as the UV sterilization process requires certain conditions, such as water clarity, as impurities and suspended solids can affect the effectiveness of the rays. It also needs maintenance, as UV systems require periodic maintenance to ensure the efficiency of the devices, as impurities can accumulate on the lamps. There are several previous studies, as the use of UV in water treatment plants has reduced the effectiveness of bacteria by up to 99%, making it an effective means of sterilization. Another study showed that UV technology helped reduce the concentration of organic chemical pollutants in treated water, demonstrating its effectiveness in water treatment[22].
Therefore, UV technology is a powerful and effective tool in water sterilization, as it helps kill microbes and organic pollutants, which helps improve water quality. However, attention must be paid to the surrounding conditions and maintenance requirements to ensure maximum effectiveness.
Ion exchange technology is one of the most prominent methods used in water treatment and removing pollutants, including heavy metals and unwanted ions. This technology relies on the use of special materials known as ion exchange materials, which are characterized by their ability to replace harmful ions in water with less harmful or harmless ions[16].
This process relies on a chemical reaction in which ions present in water such as heavy metals or toxic ions are replaced with other ions such as sodium or potassium present on the surface of the ion exchange materials. Ion exchange materials contain negative or positive charges that attract ions carrying opposite charges, which leads to the replacement of harmful ions with harmless ones. Types of ion exchange materials include silicon deposits used to remove cations (positive

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ions) such as calcium and magnesium, and lipid deposits used to remove anions (negative ions) such as chloride and nitrate [23].
Contaminated water is passed through a column containing ion exchange materials. During the passage of water, harmful ions are replaced with harmless ions present on the surface of the exchange materials. After a certain period of use, the column requires cleaning or regeneration using a solution containing certain ions to restore the effectiveness of the materials[24].

There are many benefits to using ion exchange technology, especially since it is highly effective, as ion exchange technology is very effective in removing toxic ions and heavy metals such as lead, cadmium and mercury. Improving water quality, as it improves the properties of water by reducing hardness and purifying water, as well as flexibility of use, as it can be used in various applications, from drinking water treatment to industrial water treatment, there are challenges to using ion exchange technology, such as operating costs and waste generation. Previous studies have shown that ion exchange technology can reduce the concentration of heavy metals in water by up to 95%, making it an ideal choice for treating contaminated water, other research has shown that the use of ion exchange materials has contributed to improving water quality in industrial areas that suffer from significant pollution[25].

Therefore, ion exchange treatment is an effective and flexible technology in water treatment, which contributes to removing harmful ions and improving water quality. Despite the challenges related to cost and waste management, this technology represents an important option in the fields of water and wastewater treatment.

Conclusions:

1- The emerging pollutants such as pharmaceuticals and industrial chemicals are daily rising threats to water sources because of daily use.
2- Entry routes of pollutants and diversity in entry pathways of those into water-such as sewage, agricultural runoff, and industrial discharge-make the control of pollution more difficult.
3- Difficulty in removal: Most of the pollutants resist removal by conventional treatment techniques, which demands new technologies.
4- Its actual fate in the environment is determined by complex interplay between various biological and chemical degradation, sedimentation, and evaporation processes, which in turn affect its overall concentration and distribution in water.
5- Advanced treatment technologies, such as biological treatment, nanofiltration, advanced oxidation techniques, and other advanced solutions, represent very promising methods for the removal of emerging pollutants from water sources.
6- It also points out the importance of community awareness of risks from emerging pollutants and, at the same time, the necessity of taking effective measures to reduce pollution and improve the quality of water.

Future directions for research point to the need for more studies if the full effects

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of emerging pollutants are to be known and effective strategies for their management in the environment are to be instituted.

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