**Review Article**

**An Overview of Recent Water Treatment methods**

**Abstract**

In the last few decades the concern over drinking water quality is increasing enormously in the developing countries, and the main reason behind is 80% of illness caused due to poor quality of water. Water safety and cleanliness are critical issues for both industrial and public health uses. To get rid of pollutants and pathogens, standard water treatment methods usually include a number of standard procedures, such as filtration, sedimentation, coagulation, and disinfection. However, the recent development in new & emerging water treatments have gained attention due to their substantial advantages and efficiency over the standard methods. This review paper aimed to address the in detail about drinking water resources available, causes of contamination water and methods of water treatment. The enhanced water treatment methods such as reverse osmosis, Nano filtration, Advanced Oxidation Process, Photocatalysis, Ultraviolet disinfection, Chlorine dioxide disinfection, Solar disinfection and Electro-coagulation, were discussed with their advantages and disadvantages.

**Keywords:** water treatment, disinfection, water sources, membrane filtration

**1.0 Introduction**

Every living thing on Earth depends on water to survive and thrive. It is the basic building block of life and vital to sustainable development. Globally, water is one of critical issue aligned with food security, agriculture, gender, education, and climate change on which scientific community are working rigorously for better solutions. Although water covers up to 70% of the planet's surface, its apparent abundance can be misleading (Shah et al., 2020). However, the great majority of this water is salty, making it unfit for human consumption and the majority of other uses that maintain life. Certainly, lakes and rivers, the main sources of freshwater supplies for the world's population, only make up a very small portion, approximately 0.01%, of the total (Barrenha et al., 2018). An estimated one billion people do not currently have access to a sufficient amount of drinking water due to severe lack of usable freshwater resources. This situation is made worse by the degradation of water quality brought on by pollution, contamination, and overexploitation; each year, unsafe water, sanitation, and hygiene are blamed for over 2 million deaths (Kılıçaslan et al., 2014).

However, every year, 3.6 million people die from diseases linked to poor water, sanitation, and hygiene, which account for over 10% of the global disease burden (Aydamo et al., 2023). Many people may still experience problems with water quality even though most people on the planet have access to better water sources because of contamination at the source, in distribution networks, or during handling and storage in the home (Bastaraud et al., 2018). According to UNICEF statistical report more than 2 billion people live in countries where the actual water available is less than the water required (Anonymous 2025). Climate change is also have been an alarming impact on water availability, water scarcity and contaminating water supplies. Access to improved water and sanitation is essential, as it forms the foundation for healthy communities and delivers significant health, economic, and social benefits.

In the last few decades the concern over drinking water quality is increasing enormously in the developing countries, and the main reason behind is 80% of illness caused due to poor quality of water. The consumption of contaminated water may spread different diseases such as cholera, gastroenteritis, diarrhoea, dysentery and various other viral and parasitic infections (Ali et al. 2021). World Health Organisation (WHO) reported that at least 1.7 billion people globally used a drinking water source contaminated with feces (WHO 2022). On the other hand, the freshwater sources are gradually diminishing due to the industrial and urban development. Additionally, prior estimations have indicated that the effects of poor sanitation, hygiene, and water quality go beyond diarrheal illnesses and contribute to a variety of other health problems (Prüss-Ustün et al., 2019). Developing nations bear a disproportionate amount of the burden of disease caused by these causes; 90% of the victims are children, and 99.8% of the 1.8 million deaths associated with these factors occur there (Kallman et al., 2011). Since the availability of dependable water sources is essential to public health and well-being, ensuring that everyone has access to clean drinking water continues to be a top priority on a global scale (Le et al., 2023). A basic human right and an essential element of sustainable development is having access to clean, safe drinking water. Poor water quality and water shortages remain major problems, especially in developing nations where a sizable section of the populace lacks access to clean drinking water sources (Gambe 2019): (Dinka 2018). This review article mainly comprises of following points such as drinking water sources, causes of water spoilage and different methods of water treatment and their advantages and disadvantages are also discussed.

**1.1 Drinking Water Resource**

The diversity of drinking water sources around the world encompasses both improved sources, such as piped water and protected wells, and unimproved sources, including surface water and unprotected springs (Sánchez‐Murillo et al., 2024).

**a. Surface water**

Surface water refers to all water bodies that are found above the ground, such as rivers, lakes, and reservoirs. These sources are directly exposed to the environment, making them vulnerable to pollution from industrial discharge, agricultural runoff, and domestic waste. Surface water is a primary source of drinking water in many urban areas, but it must undergo proper treatment before consumption.

**b. Groundwater**

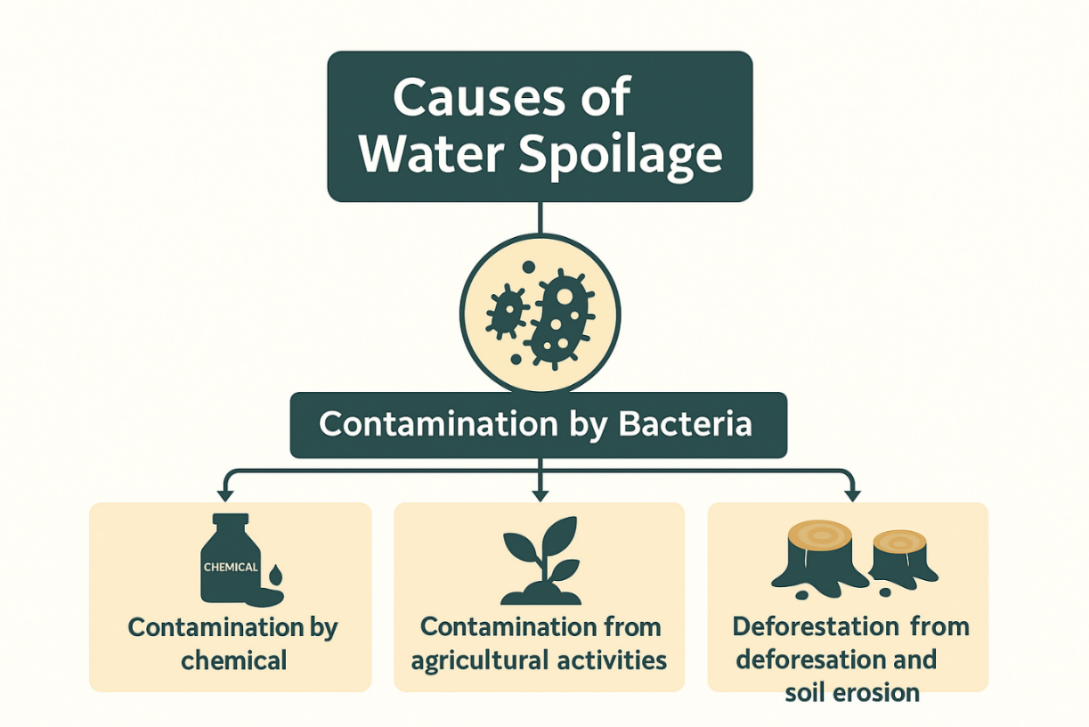
As the main source of drinking water for millions of people globally, groundwater is an essential natural resource that is essential to maintaining life on a global scale. A key element of the hydrological cycle, groundwater recharge is the process by which surface water seeps into the subsurface and replenishes the groundwater that already exists. This process has significant effects on environmental sustainability and water security. Numerous environmental elements, such as climate, topography, soil type, and geology, have an impact on groundwater recharge. Because it supplies the required water inputs to the subsurface, precipitation, both in the form of rainfall and snowmelt, is the main factor influencing groundwater recharge.Groundwater is stored in natural underground formations called aquifers. It is typically accessed through wells, boreholes, and handpumps. Due to natural filtration as it passes through soil and rock layers, groundwater is usually of better quality than surface water. However, excessive withdrawal and contamination from chemicals like fluoride and arsenic pose serious challenges in many parts of India (Anonyms 2022).

**c. Rainwater Harvesting**

Rainwater harvesting is the process of collecting and storing rainwater from rooftops or land surfaces for later use. It is a sustainable method to supplement the water supply, especially in areas with seasonal water scarcity. This method not only reduces dependency on groundwater but also helps in recharging aquifers. However, there are different ways where water get contaminated such as at water source itself, groundwater or surface water. Still, Groundwater is the prominent source of water supply in different parts of the world. Surface water is the source of water specifically for the hilly or sloppy areas.

**1.2 Causes of water Spoilage**

Water spoiling is a frequent problem that can have serious repercussions, including lowering the safety and quality of water sources, raising health issues, and damaging infrastructure. Water spoiling is caused by several circumstances, and identifying these causes is essential to creating a practical solution to lessen the issue.

****

**Causes of water spoilage**

**Fig. 1. Causes of water spoilage**

**a. Contamination by Bacteria;**

One of the top priorities for public health agencies around the world is preserving the integrity and purity of water sources. Water quality can be seriously threatened by bacteria, which can cause water to deteriorate and even cause an outbreak of waterborne illnesses (Ojo, & Oso 2018). In underdeveloped nations, where poor water and sanitation systems contribute to the spread of waterborne diseases, bacterial contamination of water sources, such as lakes and streams, is a serious problem (Motshekga et al., 2015). Microbial contamination is a major contributor to the deterioration of water (Kesari et al., 2021). Water quality can deteriorate due to the growth of pathogenic microorganisms, including Salmonella, Vibrio, and E. Coli (Aaliya et al., 2022). Poor sanitation practices, cross-contamination, and inadequate treatment are some of the ways that these microbes might enter the water supply. Apart from bacterial contamination, chemical contamination can also cause water to deteriorate. The growth of these dangerous bacteria in water can be caused by a number of factors, including poor hygiene habits, leaks in distribution systems, and insufficient water treatment. Even while water naturally neutralizes contaminants, unchecked pollution can override this self-generating ability, therefore, continuous monitoring and management of pollutant discharge into aquatic habitats is necessary (Martinengo et a., 2021). To address this issue, scientists have looked at using carbon nanotubes, metal (mainly silver) and metal oxide nanoparticles, which have been demonstrated to have potent antibacterial qualities (Motshekga et al., 2015); (Rikta , 2019).

**b. Contamination by chemical**

Maintaining the quality of water is crucial since it is a resource that is necessary for life to exist on Earth. Unfortunately, population increase, industrial activity, and other environmental variables have made water contamination a major global challenge (Khaligh et al., 2018). In this context, one of the main issues is the pollution of water supplies by different chemicals, which can have negative impacts on the ecosystem.  
In particular, groundwater is an essential resource that supplies long-term water for agriculture and acts as a source of drinking water for a sizable population. However, both natural and man-made activities are posing a growing threat to this valuable resource, as evidenced by the discovery of a number of contaminants of growing concern, including biological agents, perfluorinated compounds, pharmaceuticals, personal care items, and endocrine disruptors (Kurwadkar 2017). Chemical contaminants that can contaminate water supplies include heavy metals and industrial waste (Su et al., 2018). The extent of heavy metal available in water is originated from reservoir from where it is coming. The major source of heavy metal contamination in water is industry or laboratory waste. Although different metals are required for human body in some small amounts such as copper, zinc and chromium and their high percentage in water may contaminated water and may have severe effect on health (OB & Muchie 2010).

**c. Contamination from agricultural activities**

The quality of water supplies around the world has been significantly impacted by the intensification of agricultural operations. Because it introduces a variety of contaminants, such as excess nutrients, pesticides, and salts, irrigated agriculture in particular is a significant contributor to the contamination of surface and groundwater bodies (Bhuvaneshwari et al., 2022) (Castellar da Cunha et al., 2018). It has been demonstrated that the use of chemical fertilizers, which are typical in contemporary agricultural systems, negatively affects the quality of water. A variety of pollutants and nutrients can be introduced into adjacent water bodies by runoff from agricultural areas, changing the water's physicochemical properties, including its pH, dissolved oxygen content, and the presence of dangerous compounds. Wide-ranging effects on aquatic ecosystems and the quality of water supplies utilized for human consumption and other uses may result from this (Sunitha et al., 2013). Water quality can be negatively impacted by the usage of fertilizers, herbicides, and irrigation water, all of which are essential for agricultural output (Vital et al., 2018). When these inputs are applied excessively, residues may build up in farming soil or be carried to adjacent aquatic habitats, endangering both the environment and human health (Li et al., 2019).

**d. Contamination from deforestation and soil erosion**

Deforestation and soil erosion are inextricably intertwined, and their effects on water supply and quality are profound. Water resources are degraded by sediment and contaminants that are carried into streams by soil erosion, a natural process that is enhanced by human activity. A major worldwide problem, soil erosion is made worse by deforestation and unsustainable land-use practices (Dapin & Ella 2023). The loss of vegetation exposes the soil, increasing the likelihood that water will wash it away, a process called water erosion. In addition to removing topsoil, this erosion process also introduces silt, fertilizers, and other contaminants into adjacent bodies of water, lowering water quality and decreasing reservoir and dam storage capacity (Guerra-Rodríguez et al., 2020).

Recent developments in geospatial technologies, such as geographic information systems and remote sensing, have become effective instruments for evaluating and ranking watersheds, allowing for focused soil and water conservation measures. These studies have demonstrated how important landscape management is to preserving ecosystem resilience and health, especially in dry areas where flash floods and water scarcity are common (Khan et al., 2009).

**2.0 Method of Water Treatment**

In this paper water treatment methods are presented mainly into two types i.e. standard and enhanced. The standard methods comprises of 1) Flocculation and Coagulation and 2) Sedimentation. Furthermore, the enhanced methods includes 1) Primary such as Reverse Osmosis, Nanofiltration, Advanced Oxidation Process and Photocatalysis 2) Disinfection such as Ultraviolet, Chlorine dioxide and Solar Disinfectant 3) Embracing such as Electro-coagulation.

**2.1 Standard methods**

**2.1.1 Flocculation and Coagulation**

Governments and water authorities around the world have a fundamental duty to ensure the availability of clean, safe drinking water since access to potable water is necessary for human health, well-being, and economic growth (Jiang 2015). The process of creating a homogenous mixture by combining chemicals (coagulants) with raw water is known as coagulation. Colloidal particles will be drawn to one another and cluster together to form a flock by coagulation. If simply by gravity deposition, the colloidal particles that are created are typically too difficult to eliminate. However, if the Aggregation or coagulation into larger particles stabilizes colloids, they can be swiftly removed (Margaretha et al., 2012). The chemical process of coagulation is employed to eliminate particles that may contribute to environmental contamination. Physically handling of these particles is challenging since they are unable to settle. A microflow will occur when the particles become unstable due to the presence of a coagulant. After that, the microfloc is coagulated to form macroflocs that can be flocculated and distributed. Slow stirring in water and patience are key components of this clotting process. After the coagulation process, the flocculation period typically lasts 10 to 30 minutes. Both flocculation and coagulation are commonly employed in drinking water treatment facilities. It was observed that this method of water treatment is most suitable for the water with metal concentration higher than 1000 mg/L (Zinicovscaia 2016). The goal is to increase the sedimentation stage's capacity to use gravity to remove suspended debris and contaminants. Agglomerating, destabilizing, and neutralizing the charge of the suspended components are the steps involved in this process. This method combines chemical and physical reactions. The solubility of coagulants is significantly impacted by the pH of the water, which also affects how well mineral salts hydrolyze and remove organic debris. When iron salts and amorphous aluminum hydroxide precipitate, the pH range of 5 to 8 is optimal (Febrina et al., 2020).

**2.2 Sedimentation**

A vital step in the treatment of water is sedimentation, which involves removing solids and suspended particles from the water. In a water treatment facility, this procedure is usually the first one when the influent water is permitted to slow down and settle so that the heavier particles can drop to the bottom (Wang & Peng 2010). One example of an undesired small particle-suspended substance is sand, silt, and clay. These are extracted from water using gravity. Together with a few biological pollutants. As the water sediments over a longer period of time, more germs and suspended materials will drop to the bottom (Hofman-Caris & Hofman 2019). When very turbid waters are treated with sedimentation, water treatment facilities can use a uniformly low turbidity water supply, which makes plant operations easier. In addition to lowering chemical expenses by as much as 70%, this guarantees that the particles in the filter's influent have been successfully eliminated or have had their size and concentration decreased (O'Melia 1985).

**2.3 Advantages of standard water treatment**

In order to guarantee that people everywhere have access to safe and clean drinking water, water treatment is an essential procedure. Before being released into water bodies, raw water sources are converted into drinking water, and wastewater into treated effluent using a variety of treatment methods. In particular, drinking water and wastewater treatment are crucial components of the water cycle in human life (Kurniawan et al., 2020). Coagulation and flocculation are two crucial treatment methods that have been used in water treatment for many years. (Ang & Mohammad 2020). It was reported that the microplastics are more effectively removed during the coagulation and sand filtration (sedimentation) processes. The coagulation efficiency is influenced by the kind of coagulant employed as well as the properties of the water (such as pH). Therefore, the enhanced elimination of larger-sized microplastics during coagulation/sedimentation was probably driven by the flocs' higher attachment likelihood, which improved settling. FeCl3 and AlCl3 could successfully eradicate microplastics. It is also observed that the algal development is eliminated after a sand filtering system, due to the high cyanobacteria removal rate of coagulation and flocculation processes. Additionally, this kind of process allows for a decrease in the generation of precursors for putative disinfection by-products (Febrina et al., 2020).

**2.4 Disadvantages of standard water treatment-**

One of the biggest drawbacks of standard water treatment is its possible environmental impact. Chemical coagulants may create undesirable reactions in treated water, resulting in extra pollution. Furthermore, the process generates vast amounts of sludge, which requires adequate disposal and can pose a considerable burden on the overall treatment system**.** Likewise, the disadvantage is the need for chemical reagents (e.g., aluminium or ferric salts), which increases the technology's operating expenses. To achieve optimal flocculation, considerable volumes of coagulant and flocculant may be required. Additionally, some physicochemical sludge is created, which is normally treated outside. Installing a sedimentation basin is simple and cost-effective. A sedimentation basin requires a significant amount of room. Sedimentation basins are designed based on their maximal volume

Enhanced technologies are necessary to eliminate developing pollutants from drinking water due to the extensive use of chemicals, pharmaceuticals, pesticides, and solvents. Standard treatment methods are not designed to do so (Arslan et al., 2016).

**3.0 Enhanced Water Treatment**

Water safety and cleanliness are critical issues for both industrial and public health uses. To get rid of pollutants and pathogens, standard water treatment methods usually include a number of procedures, such as filtration, sedimentation, coagulation, and disinfection (Pakharuddin et al., 2021). Nevertheless, these conventional techniques can be costly and chemically demanding, producing hazardous disinfection byproducts. To overcome these constraints, a number of cutting-edge methods for efficient water disinfection have been investigated.

**Fig. 2. Enhanced Water Treatment methods**

**3.1 Reverse osmosis**

In the field of drinking water treatment, reverse osmosis is a very successful water filtration technique hence it is becoming more and more common. This method produces high-quality, drinkable water by selectively filtering away dissolved salts, minerals, and other impurities from water using a semipermeable membrane (Buzzi et al., 2013). It works best to get rid of pesticides and other pollutants, including cyanide compounds and heavy metals. Among the dissolved solutes that the RO system may extract from water are single-charged ions like Na+ and (Cl-). Maintaining & preventing recontamination of drinking water inside the distribution system, and inactivation of bacteria, viruses and protozoa etc. present in raw water all depend on disinfecting the water. By the use of a semipermeable barrier that allows water to flow through rather than the dissolved substance (Rodriguez-Mozaz et al., 2015). The solution-diffusion mechanism, which is a diffusion-controlled process, can be used to conceptualize the mass transfer of permeant over RO membranes. Through the solution-diffusion mechanism, permeants dissolve in the membrane material and then diffuse across it. Water may easily enter and exit the membrane polymer structure because of the RO membrane's high hydrophilicity. RO is responsible for the removal of around 97% of all organic and inorganic organisms from surface and groundwater (Rodríguez‐Chueca et al., 2015).

**3.2 Nanofiltration membrane**

It is impossible to overestimate the significance of supplying clean, safe drinking water because it is a necessary resource for maintaining life. The creation of novel and effective water treatment techniques has become essential due to the rising incidence of waterborne illnesses brought on by different organic, inorganic, and microbiological contaminants (Figoli et al., 2017). In order to overcome these issues, nanotechnology has emerged as a promising field with the potential to completely transform how we treat and purify water (Thines et al., 2017). Membrane filtration is an efficient way to remove particles, germs, and organic matter from drinking water and wastewater. Contrasting membrane procedures with conventional therapeutic methods. It can provide better-quality water, lessen the need for disinfectants, compress water more easily, provide simpler operational management, require less upkeep, and generate less dirt. The most efficient membrane techniques for eliminating novel pollutants include ultrafiltration, nanofiltration, and reverse osmosis due to their small pore sizes. (Kumar & Pandit 2012). Several scientist found that (Mijatović, et al., 2004); (Costa & De Pinho 2006) & (Khalik & Praptowidodo 2000) & (Guo et al., 2022) nanofiltration method is most suitable for removal of organic matter from groundwater, surface water and brackish water etc.

**3.3 Advanced oxidation process**

As global concerns about water pollution, water shortages, and the need for sustainable water management techniques increase, the development of water treatment technology has become increasingly important. The use of advanced oxidation processes, which have garnered significant interest in the water treatment industry, is one such innovative strategy (Paumo et al., 2021). Near-ambient temperature and pressure water treatment methods known as "advanced oxidation processes" generate highly reactive hydroxyl radicals that can effectively degrade a range of organic pollutants in water and wastewater (Pandey et al., 2015). Depending on various factors, such as the solids concentration in the water, its purity, and the potential for fouling during the treatment process, these radicals can be produced by simultaneously introducing multiple oxidants. Systems utilize peracetic acid, UV radiation, hydrogen peroxide, and ozone to mitigate this issue. Advanced oxidation techniques present a very effective treatment strategy because they can simultaneously eliminate biological contaminants and resistant organic compounds. One advantage of advanced oxidation techniques over traditional disinfection methods is that they do not produce disinfection byproducts.

**3.4 Photocatalysis**

Photocatalysis has emerged as a viable method in the field of water treatment due to the growing incidence of water pollution and the need for sustainable water purification methods. Due to its great efficiency, affordability, and environmental friendliness, photocatalysis a process that breaks down organic contaminants using light-activated catalysts has attracted a lot of attention in recent decades (Kabra et al., 2004) Since its discovery in 1973, heterogeneous photocatalysis more especially, the use of TiO2 has seen constant development. By using clean, renewable solar energy to create strong oxidizing agents that can efficiently break down a variety of organic pollutants and harmful microorganisms found in wastewater, this technology presents a competitive alternative to energy-intensive standard treatment techniques (Mitoraj et al., 2018); (Kabra et al., 2004).

**3.5 Disinfection Techniques**

Disinfection is often the final stage in drinking water treatment, with the goal of getting rid of the harmful microbes that make people sick when they drink tainted water. These include the process's ability to produce a residue that provides an extra line of defense against potential post-treatment contamination caused by distribution system flaws; the treated water's aesthetic quality; its efficacy against helminths, viruses, bacteria, and protozoa as aquatic pathogens; the level of precision with which the procedure can be observed and managed; and the technological ability to perform the procedure on the scale required for public water supplies. In order to eradicate pathogens from the raw water supply and lower the possibility of recontamination during storage and distribution, disinfection is feasible (Pichel et al., 2019). However, disinfection is a standard method of water treatment but here are some advance methods of water disinfection is presented.

**3.5.1 Ultraviolet Disinfection**

An efficient method of disinfection that eliminates the need for heat to eradicate bacteria using UV irradiation (Chauhan et al., 2018). In the industrialized world, ultraviolet (UV) is a popular disinfection method for water treatment. Most germs are rendered inactive by an adequate amount of ultraviolet light. Similar to regular fluorescent bulbs, ultraviolet light is created when an electric arc strikes mercury or, more recently, xenon vapor. Between 100 and 400 nanometers (nm) is the UV spectrum, with   
The best wavelength for disinfecting microorganisms is between 200 and 280 nm. Bacterial spores and viruses, particularly adenoviruses, are the most UV-resistant species.. Additionally, the protozoan Acanthamoeba has a high level of UV resistance. Giardia and Cryptosporidium bacteria and cysts are particularly vulnerable. Like any disinfectant, the process involves dosage and contact duration, with varying effects on different organisms. Millijoules per square centimeter is the unit of measurement for UV dose. You can raise the transmittance of the water, lower the distance to the light, increase the output of the lamp, or slow the flow through the reaction chamber to increase the dose (Paidalwar & Khedikar, 2016).

**3.5.2 Chlorine dioxide disinfection**

The Chemical compound, like chlorine dioxide, which has the molecular formula ClO₂, has attracted a lot of interest in the field of water treatment because of its special qualities and adaptability in solving a range of water purification problems. Chlorine dioxide has a wider range of antibacterial action than conventional disinfectants based on chlorine, and it may efficiently inactivate a variety of pathogens, such as bacteria, viruses, and protozoa (Anastasi et al., 2013)

Chlorine dioxide can disinfect drinking water and remove dangerous pathogens, including bacteria, fungi, and viruses, from fruits and vegetables without sacrificing their taste. For more than 50 years, chlorine dioxide has been added to drinking water in the US and is occasionally used in place of other treatment techniques. Since chlorine dioxide kills bacteria even at low concentrations, it is recommended as a disinfectant. Chlorine dioxide can be used to treat water for a number of reasons, including reducing the number of harmful organisms present or improving the water's quality by eliminating contaminants (Qadri & Alam 2024).

**3.5.3 Solar disinfectant**

A straightforward and affordable way to produce drinking water is through solar thermal disinfection. In order to inactivate or eliminate pathogen microorganisms, it uses solar energy to heat water to a high enough temperature for a predetermined amount of time (Pichel et al., 2019). Solar-powered water disinfection has been practiced since ancient Egypt. The process was initially examined and documented in scientific literature in the late 1870s by scientists Downes and Blunt, who were stationed in London. Utilizing the antibacterial properties of sun radiation, solar disinfection (SODIS) purifies water. Its foundations include thermal heating, the oxidative activity linked to dissolved oxygen, and the germicidal action of UV light. The technique is straightforward and reasonably priced, and it is dependent on temperature, water turbidity, radiation intensity, and water height. It entails putting water in clear plastic bottles typically made of Polyethylene Terephthalate (PET )and letting them sit in the sun for at least six hours (Queluz & Sánchez-Román 2014). The primary advantages of solar disinfection are its independence from chemical components and electricity, its low operating and maintenance costs (the user must pay for the PET bottles, which need to be changed every six months), its minimal impact on the water's flavor and odor, and its ability to produce no residue (Oates et al., 2003).

|  |  |  |  |
| --- | --- | --- | --- |
| **Method** | **Advantages** | **Disadvantages** | **References** |
| **Reverse osmosis-** | 99% salt removal efficiency and several metal removals at the same time. | Filter changes and routine maintenance are required.  The cost of installing a reverse osmosis system is high. The entire procedure is really slow. | Qadri & Alam (2024). |
| **Nanofiltration membarne** | Compared to standard materials, nanofiltration offers more active sites for pollutant removal due to its high surface area to volume ratios. | Compared to standard approaches, implementing water treatment systems based on nanotechnology may require a substantial upfront expenditure**.** | Figoli et al., (2017). |
| **Advanced oxidation process** | AOPs can degrade pharmaceuticals, dyes, pesticides, and endocrine-disrupting compounds that resist conventional treatment**.** | High operational cost while Using of UV, ozone, or H₂O₂ increases energy and chemical consumption. | Mishra et al., (2017). |
| **Photocatalysis -** | TiO2 and ZnO as photocatalysts offers many advantages such as affordability, environmental friendliness, and chemical and physical stability**.** | Preparing a novel photocatalyst is a time-consuming procedure that typically calls for significant cost outlays**.** | Kabra et al., (2004). |
| **Ultraviolet Disinfection** | The technique avoids chemical additives, ensuring that no residual taste or by-products are left in the treated water. | Some organisms, such as adenoviruses and bacterial spores, are more resistant to UV light and require higher doses or supplementary treatment steps. | (Paidalwar & Khedikar 2016)  (Kumar & Pandit 2012) |
| **Chlorine dioxide disinfection** | Chlorine dioxide is effective at inactivating a wide range of microorganisms including bacteria, viruses, and protozoa, even when used at low concentrations. | Chlorine dioxide is sensitive to factors like temperature and light exposure. Variations in these conditions can affect its stability and disinfection efficacy, which may require additional safeguards during storage and operation. | Malik, & Kumar (2024). |
| **Solar disinfectant** | Since it relies on natural sunlight, no chemical additives are needed. This prevents the formation of harmful chemical residues and preserves the natural taste of the water. | The effectiveness of SODIS is closely tied to weather conditions. Cloudy days, rainy seasons, or low sun angles can significantly reduce disinfection efficiency due to insufficient UV radiation | Gupta et al., (2013) |
| **Electro-coagulation (EC)** | It can handle variety of contaminants, does not pose any risk of secondary contaminant generation unlike chemical coagulation. | The use of either Al or Fe electrodes for pollutant removal does not always attain com-  plete removal. EC may face problem in removing biodegradable  and soluble organic pollutants. | Das et al., (2022); Mao et al., (2023) |

**Table 1. Advantages and disadvantages of different enhanced water treatment methods**

**3.6. Electro-coagulation (EC)**

Electrocoagulation provides a less costly alternative to conventional activated sludge methods and general chemical coagulation, which depend on chemicals and microorganisms for their tertiary treatment. Electrocoagulation, which creates coagulants electrically using metal electrodes, simplifies and ensures the coagulation process. Metal electrodes generate cations during electrocoagulation when exposed to an electric field. From ion production to floc formation, there are seven sequential steps (Chen et al., 2005). The contaminated colloidal particles attract the dissociated metal ions, which counterbalance their charge and enable coagulation. The H2 gas that has been released from the cathode electrode then works with the particles, causing flocculation, which enables the superfluous material to rise and subsequently separate. Many readily available and reasonably priced metals, including iron, aluminium, and stainless steel, have been used as electrodes. (Karkhaneh, & Keshmirizadeh 2015). EC uses electric current to destabilize contaminants in electrolytic solutions, either dissolved or suspended. Electrocoagulation uses an electrolytic cell with sacrificial metal electrodes (often Fe or Al) connected to a regulated DC power source. Cathodes and anodes used in the process might be produced from similar or distinct materials. (Sadaf et al., 2024). An electrocoagulation reactor consists of an electrolytic cell with a single anode and cathode. When the cell is connected to an external power source, the anode material undergoes electrochemical corrosion due to oxidation. The conductive metal plates are generally called as' sacrificial electrodes' and can be made of the same or different materials, such as Fe electrode. (Islam 2019). EC is based on the concept of "electrolysis," which refers to the use of electricity to separate compounds. When an electrolytic solution is exposed to electrical current, oxidation and reduction reactions occur. In 1820 (Chen et al., 2005). An electrolyte, water, or salt-melting solution can move ions between two electrodes. When an electrical current is applied, positive ions travel to the cathode and negative ions to the anode. At electrodes, cations are reduced while anions are oxidized. (Sahu et al., 2014).

**4.0 Conclusions**

The review paper presented the different causes of water spoilage its effect on human, environment and solution to these problem also discussed. Different standard and enhanced water treatment such as filtration, coagulation and sedimentation and reverse osmosis, Nano filtration, Advanced Oxidation Process, Photocatalysis, Ultraviolet disinfection, Chlorine dioxide disinfection, Solar disinfection and Electro-coagulation reviewed thoroughly. It was found that the process such as photocatalysis, nanofilatrtion are very new and have great potential to remove toxic and inorganic material from wastewater. The study concluded that the combination of electro-coagulation with other methods such as ultrafiltration, nanofiltration, and reverse osmosis help to remove the novel pollutants from water.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

**References**

1. Shah, A. I., Dar, M. U. D., Bhat, R. A., Singh, J. P., Singh, K., & Bhat, S. A. (2020). Prospectives and challenges of wastewater treatment technologies to combat contaminants of emerging concerns. Ecological Engineering, 152, 105882.
2. Barrenha, P. I. I., Tanaka, M. O., Hanai, F. Y., Pantano, G., Moraes, G. H., Xavier, C., ... & Mozeto, A. A. (2018). Multivariate analyses of the effect of an urban wastewater treatment plant on spatial and temporal variation of water quality and nutrient distribution of a tropical mid-order river. Environmental monitoring and assessment, 190, 1-16.
3. Kılıçaslan, Y., Tuna, G., Gezer, G., Gulez, K., Arkoc, O., & Potirakis, S. M. (2014). ANN-based estimation of groundwater quality using a wireless water quality network. International Journal of Distributed Sensor Networks, 10(4), 458329.
4. Aydamo AA, Gari SR, Mereta ST. Access to Drinking Water, Sanitation, and Hand Hygiene Facilities in the Peri-Urban and Informal Settlements of Hosanna Town, Southern Ethiopia. Environmental Health Insights. 2023;17. doi:10.1177/11786302231193604
5. Bastaraud, A., Rakotondramanga, J. M., Mahazosaotra, J., Ravaonindrina, N., & Jambou, R. (2018). Environmental factors and the microbial quality of urban drinking water in a low-income country: The case of Madagascar. *Water*, *10*(10), 1450.
6. Prüss-Ustün, A., Wolf, J., Bartram, J., Clasen, T., Cumming, O., Freeman, M. C., ... & Johnston, R. (2019). Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low-and middle-income countries. International journal of hygiene and environmental health, 222(5), 765-777.
7. Kallman, E. N., Oyanedel-Craver, V. A., & Smith, J. A. (2011). Ceramic filters impregnated with silver nanoparticles for point-of-use water treatment in rural Guatemala. *Journal of Environmental Engineering*, *137*(6), 407-415.
8. Ojo, O. A., & Oso, B. A. (2008). Isolation and characterization of synthetic detergentdegraders from wastewater. African Journal of Biotechnology, 7(20).
9. Motshekga, S. C., Ray, S. S., Onyango, M. S., & Momba, M. N. (2015). Preparation and antibacterial activity of chitosan-based nanocomposites containing bentonite-supported silver and zinc oxide nanoparticles for water disinfection. Applied Clay Science, 114, 330-339.
10. Kesari, K. K., Soni, R., Jamal, Q. M. S., Tripathi, P., Lal, J. A., Jha, N. K., ... & Ruokolainen, J. (2021). Wastewater treatment and reuse: a review of its applications and health implications. Water, Air, & Soil Pollution, 232, 1-28
11. Aaliya, B., Sunooj, K. V., Navaf, M., Akhila, P. P., Sudheesh, C., Sabu, S., ... & George, J. (2022). Influence of plasma-activated water on the morphological, functional, and digestibility characteristics of hydrothermally modified non-conventional talipot starch. *Food Hydrocolloids*, *130*, 107709.
12. Martinengo, M., Ziantoni, A., Lazzeri, F., Rosatti, G., & Rigon, R. (2021). A practitioners’ view on the application of the water framework directive and the Floods Directive in Italy. In *Water Law, Policy and Economics in Italy: Between National Autonomy and EU Law Constraints* (pp. 369-393). Cham: Springer International Publishing.
13. Motshekga, S. C., Ray, S. S., Onyango, M. S., & Momba, M. N. (2015). Preparation and antibacterial activity of chitosan-based nanocomposites containing bentonite-supported silver and zinc oxide nanoparticles for water disinfection. *Applied Clay Science*, *114*, 330-339.
14. Khaligh, N. G., & Johan, M. R. (2018). Recent application of the various nanomaterials and nanocatalysts for the heavy metals’ removal from wastewater. Nano, 13(09), 1830006.
15. Kurwadkar, S. (2017). Groundwater pollution and vulnerability assessment. Water Environment Research, 89(10), 1561-1577.
16. Su, H. C., Liu, Y. S., Pan, C. G., Chen, J., He, L. Y., & Ying, G. G. (2018). Persistence of antibiotic resistance genes and bacterial community changes in drinking water treatment system: from drinking water source to tap water. Science of the Total Environment, 616, 453-461.
17. Bhuvaneshwari, S., Majeed, F., Jose, E., & Mohan, A. (2022). Different treatment methodologies and reactors employed for dairy effluent treatment-A review. Journal of Water Process Engineering, 46, 102622.
18. Castellar da Cunha, J. A., Arias, C. A., Carvalho, P., Rysulova, M., Montserrat Canals, J., Pérez Luque, G., ... & Farreras, J. (2018). WETWALL-an innovative design concept for the treatment of wastewater at an urban scale.
19. Sunitha, D., Murthy, S. M., Divya, K. S., & Ramalingam, A. (2013). Assessment of physico-chemical and bacteriological parameters of drinking water from different sources in Mysore City. International Journal of Innovative Research in Science, Engineering and Technology, 2(10).
20. Vital, M., Daval, D., Clément, A., Quiroga, S., Fritz, B., & Martinez, D. E. (2018). Importance of accessory minerals for the control of water chemistry of the Pampean aquifer, province of Buenos Aires, Argentina. Catena, 160, 112-123.
21. Li, X., Liu, X., Lin, C., Zhang, H., Zhou, Z., Fan, G., ... & Ouyang, W. (2019). Activation of peroxymonosulfate by magnetic catalysts derived from drinking water treatment residuals for the degradation of atrazine. Journal of hazardous materials, 366, 402-412.
22. Khan, S., Ahmad, I., Shah, M. T., Rehman, S., & Khaliq, A. (2009). Use of constructed wetland for the removal of heavy metals from industrial wastewater. Journal of environmental management, 90(11), 3451-3457.
23. Dapin, I. G., & Ella, V. B. (2023). GIS-based soil erosion risk assessment in the Watersheds of Bukidnon, Philippines using the RUSLE model. Sustainability, 15(4), 3325.
24. Guerra-Rodríguez, S., Oulego, P., Rodríguez, E., Singh, D. N., & Rodríguez-Chueca, J. (2020). Towards the implementation of circular economy in the wastewater sector: Challenges and opportunities. Water, 12(5), 1431.
25. Le, J. T., Gonzalez, J. P., Carson, R. T., Ambrose, R. F., & Levin, L. A. (2023). Integrating non-targeted ecosystem services into assessment of natural stormwater treatment systems. Water, 15(8), 1460.
26. Gambe, T. R. (2019). The gender dimensions of water poverty: exploring water shortages in Chitungwiza. Journal of poverty, 23(2), 105-122.
27. Dinka, M. O. (2018). Safe drinking water: concepts, benefits, principles and standards. Water challenges of an urbanizing world, 163.
28. Sánchez‐Murillo, R., Ortega, L., Vreča, P., Žagar, K., Shrestha, S., Kgotlaebonywe, C., ... & Miller, J. (2024). Tracing Urban Drinking Water Sources: Global State of the Art and Insights From an IAEA‐Coordinated Research Project. Hydrological Processes, 38(10), e15312.
29. Jiang, J. Q. (2015). The role of coagulation in water treatment. Current Opinion in Chemical Engineering, 8, 36-44.
30. Margaretha, Rizka Mayasari, Syaiful, Subroto, 2012, Pengaruh kualitas air baku terhadap Dosis dan biaya koagulan aluminium sulfat dan poly aluminium chloride, Jurnal Teknik Kimia Universitas Sriwijaya vol 18 no.4)
31. Febrina, W., & Mesra, T. (2020). Optimum Dosage of Coagulant and Flocculant on Sea Water Purification Process Optimum Dosage of Coagulant and Flocculant on Sea Water Purification Process.
32. Ang, W. L., & Mohammad, A. W. (2020). State of the art and sustainability of natural coagulants in water and wastewater treatment. Journal of Cleaner production, 262, 121267.
33. Wang, S., & Peng, Y. (2010). Natural zeolites as effective adsorbents in water and wastewater treatment. Chemical engineering journal, 156(1), 11-24.
34. Hofman-Caris, R., & Hofman, J. (2019). Limitations of conventional drinking water technologies in pollutant removal. Applications of Advanced Oxidation Processes (AOPs) in drinking water treatment, 21-51.
35. O'Melia, C. R. (1985). Particles, pretreatment, and performance in water filtration. Journal of Environmental Engineering, 111(6), 874-890.
36. Kurniawan, S. B., Abdullah, S. R. S., Imron, M. F., Said, N. S. M., Ismail, N. I., Hasan, H. A., ... & Purwanti, I. F. (2020). Challenges and opportunities of biocoagulant/bioflocculant application for drinking water and wastewater treatment and its potential for sludge recovery. International journal of environmental research and public health, 17(24), 9312.
37. Arslan, S., Eyvaz, M., Gürbulak, E., & Yüksel, E. (2016). A review of state-of-the-art technologies in dye-containing wastewater treatment–the textile industry case. Textile wastewater treatment, 1-29.
38. Pakharuddin, N. H., Fazly, M. N., Sukari, S. A., Tho, K., & Zamri, W. F. H. (2021, October). Water treatment process using conventional and advanced methods: A comparative study of Malaysia and selected countries. In IOP Conference Series: Earth and Environmental Science (Vol. 880, No. 1, p. 012017). IOP Publishing.
39. Buzzi, D. C., Viegas, L. S., Rodrigues, M. A. S., Bernardes, A. M., & Tenório, J. A. S. (2013). Water recovery from acid mine drainage by electrodialysis. Minerals Engineering, 40, 82-89.
40. Rodriguez-Mozaz, S., Chamorro, S., Marti, E., Huerta, B., Gros, M., Sànchez-Melsió, A., ... & Balcázar, J. L. (2015). Occurrence of antibiotics and antibiotic resistance genes in hospital and urban wastewaters and their impact on the receiving river. Water research, 69, 234-242.
41. Rodríguez‐Chueca, J., Ormad, M. P., Mosteo, R., Sarasa, J., & Ovelleiro, J. L. (2015). Conventional and advanced oxidation processes used in disinfection of treated urban wastewater. Water Environment Research, 87(3), 281-288.
42. Figoli, A., Dorraji, M. S. S., & Amani-Ghadim, A. R. (2017). Application of nanotechnology in drinking water purification. In Water purification (pp. 119-167). Academic Press.
43. Thines, R. K., Mubarak, N. M., Nizamuddin, S., Sahu, J. N., Abdullah, E. C., & Ganesan, P. (2017). Application potential of carbon nanomaterials in water and wastewater treatment: a review. Journal of the Taiwan Institute of Chemical Engineers, 72, 116-133.
44. Kumar, J. K., & Pandit, A. B. (2012). Drinking water disinfection techniques.
45. Paumo, H. K., Dalhatou, S., Katata-Seru, L. M., Kamdem, B. P., Tijani, J. O., Vishwanathan, V., ... & Bahadur, I. (2021). TiO2 assisted photocatalysts for degradation of emerging organic pollutants in water and wastewater. Journal of Molecular Liquids, 331, 115458.
46. Pandey, P. K., Sharma, S. K., & Sambi, S. S. (2015). Removal of lead (II) from waste water on zeolite-NaX. Journal of Environmental Chemical Engineering, 3(4), 2604-2610.
47. Kabra, K., Chaudhary, R., & Sawhney, R. L. (2004). Treatment of hazardous organic and inorganic compounds through aqueous-phase photocatalysis: a review. Industrial & engineering chemistry research, 43(24), 7683-7696.
48. Mitoraj, D., Lamdab, U., Kangwansupamonkon, W., Pacia, M., Macyk, W., Wetchakun, N., & Beranek, R. (2018). Revisiting the problem of using methylene blue as a model pollutant in photocatalysis: The case of InVO4/BiVO4 composites. Journal of Photochemistry and Photobiology A: Chemistry, 366, 103-110.
49. Qadri, A., & Alam, M. (2024). Drinking water treatment using advanced technologies. Int. J. Chem. Biochem. Sci., 25(14), 154-163.
50. Chauhan, N., Singh, J., Chandra, S., Chaudhary, V., & Kumar, V. (2018). “Non-thermal techniques: Application in food industries” A review. Journal of Pharmacognosy and Phytochemistry, 7(5), 1507-1518.
51. Paidalwar, A. A., & Khedikar, I. P. (2016). Overview of water disinfection by UV technology–A review. International Journal of Science Technology & Engineering, 2(9), 213-219.
52. Anastasi, E. M., Wohlsen, T. D., Stratton, H. M., & Katouli, M. (2013). Survival of Escherichia coli in two sewage treatment plants using UV irradiation and chlorination for disinfection. Water research, 47(17), 6670-6679.
53. Pichel, N., Vivar, M., & Fuentes, M. (2019). The problem of drinking water access: A review of disinfection technologies with an emphasis on solar treatment methods. Chemosphere, 218, 1014-1030.
54. Queluz, J. G. T., & Sánchez-Román, R. M. (2014). Efficiency of domestic wastewater solar disinfection in reactors with different colors. Water Utility Journal, 7(1), 35-44.
55. Oates, P. M., Shanahan, P., & Polz, M. F. (2003). Solar disinfection (SODIS): simulation of solar radiation for global assessment and application for point-of-use water treatment in Haiti. Water research, 37(1), 47-54.
56. Azin Karkhaneh, Elham Keshmirizadeh 2015 Removal of Crude Oil from Oily Artificial Wastewater by Using Pulse Electrochemical Treatment, Journal of Applied Chemical Research, Special issue, pp 55-65
57. Anonymous (2025). UNICEF report. Last accessed on December 2024. <https://www.unicef.org/wash/water>.
58. Ali, S., Amir, S., Ali, S., Rehman, M. U., Majid, S., & Yatoo, A. M. (2021). Water pollution: Diseases and health impacts. In Freshwater Pollution and Aquatic Ecosystems (pp. 1-23). Apple Academic Press.
59. Zinicovscaia, I. (2016). Conventional methods of wastewater treatment. *Cyanobacteria for bioremediation of wastewaters*, 17-25.
60. (Anonyms 2022). Report onNational Compilation on Dynamic Ground Water Resources of India. Central Ground Water Board (CGWB), Ministry of Jal Shakti. (2022). Last accessed on November 2024 (chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://static.pib.gov.in/WriteReadData/userfiles/file/GWRA2022(1)HIDO.pdf)
61. Rikta, S. Y. (2019). Application of nanoparticles for disinfection and microbial control of water and wastewater. *Nanotechnology in water and wastewater treatment*, 159-176.
62. OB, A., & Muchie, M. (2010). Remediation of heavy metals in drinking water and wastewater treatment systems: processes and applications. Int. J. Phys. Sci, 5, 1807-1817.
63. Mijatović, I., Matošić, M., Černeha, B. H., & Bratulić, D. (2004). Removal of natural organic matter by ultrafiltration and nanofiltration for drinking water production. Desalination, 169(3), 223-230.
64. Costa, A. R., & De Pinho, M. N. (2006). Performance and cost estimation of nanofiltration for surface water treatment in drinking water production. Desalination, 196(1-3), 55-65.
65. Khalik, A., & Praptowidodo, V. S. (2000). Nanofiltration for drinking water production from deep well water. Desalination, 132(1-3), 287-292.
66. Guo, H., Li, X., Yang, W., Yao, Z., Mei, Y., Peng, L. E., & Tang, C. Y. (2022). Nanofiltration for drinking water treatment: a review. Frontiers of Chemical Science and Engineering, 1-18.
67. Islam, S. D. U. (2019). Electrocoagulation (EC) technology for wastewater treatment and pollutants removal. *Sustainable Water Resources Management*, *5*(1), 359-380
68. Gao, P., Chen, X., Shen, F., & Chen, G. (2005). Removal of chromium (VI) from wastewater by combined electrocoagulation–electroflotation without a filter. *Separation and purification technology*, *43*(2), 117-123.
69. Sahu, O., Mazumdar, B., & Chaudhari, P. K. (2014). Treatment of wastewater by electrocoagulation: a review. *Environmental science and pollution research*, *21*, 2397-2413.
70. Sadaf, S., Roy, H., Fariha, A., Rahman, T. U., Tasnim, N., Jahan, N., ... & Islam, M. S. (2024). Electrocoagulation-based wastewater treatment process and significance of anode materials for the overall improvement of the process: A critical review. Journal of Water Process Engineering, 62, 105409.
71. Mishra, N. S., Reddy, R., Kuila, A., Rani, A., Mukherjee, P., Nawaz, A., & Pichiah, S. (2017). A review on advanced oxidation processes for effective water treatment. *Curr. world environ*, *12*(3), 270-490.
72. Malik, N., & Kumar, R. (2024). A Comparative Study of Different Disinfection Processes, and Management Practices to Control the Formation of Disinfection by-Products (DBPs). In *Drinking Water Disinfection By-products: Sources, Fate and Remediation* (pp. 59-83). Cham: Springer Nature Switzerland.
73. Gupta, B., Sonkar, N., Bhalavi, B. S., & Edla, P. J. (2013). Design, construction and effectiveness analysis of hybrid automatic solar tracking system for amorphous and crystalline solar cells. *American journal of engineering research*, *2*(10), 221-228.
74. Das, P. P., Sharma, M., & Purkait, M. K. (2022). Recent progress on electrocoagulation process for wastewater treatment: A review. Separation and Purification Technology, 292, 121058.
75. Mao, Y., Zhao, Y., & Cotterill, S. (2023). Examining current and future applications of electrocoagulation in wastewater treatment. Water, 15(8), 1455.