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Review

Insights into the Domestic Wastewater Treatment (DWWT) Regimes: A Review

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Abstract: It is expected that, by 2050, the rapid rise in population and simultaneous urbanization shall deplete clean water supplies. Domestic wastewater (DWW) contains inorganic and organic components that can be harmful to aquatic organisms. Traditional remediation approaches (physical, chemical and biological) can be used on-site or off-site to purify polluted domestic water (activated sludge, built-wetlands, stabilization ponds, trickling filters and membrane bioreactors), and each has its own advantages and limitations. Biosorption through microorganisms, bacteria (microbe-mediated remediation), fungi (mycoremediation) and algae (phycoremediation) has shown promising results in removing toxic chemicals and nutrients. The type of waste and its concentration, heterogeneity level and percentage of clean-up required; and the feasibility of the clean-up technique and its efficiency, practicability, operational difficulties, environmental impact and treatment costs are all factors that are to be considered when choosing a technique for domestic wastewater treatment (DWWT). This review focuses on the roles of conventional methods in DWWT, including their merits, demerits and future prospects. It promotes the concept of "reduce, reuse and recycle" of DWWT and also highlights the problem of emerging contaminants in WWT regimes. We provide insights into the different membrane filtration procedures and water purification techniques and the synergism of conventional and non-conventional WWT strategies for human and environment health security.

Keywords: activated sludge; trickling filters; bio-sorption; wastewater; conventional method

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1. Introduction

As is known to the world, water is "the elixir of life" and a valuable resource for agricultural, industrial and domestic purposes. However, the fact that we have only limited access to safe freshwater is also true [1,2]. This rising water scarcity all over the world has stimulated the reuse of treated wastewater (WW). The global water use has escalated by a factor of six in the last hundred years and will be increasing slowly at a rate of 1% per year. Moreover, variability in rainfall patterns, the rapidly increasing population, urbanization and industrialization have aggravated the issue of water security [3,4].

The practice of protecting and maintaining drinking water quality came into effect several hundred years ago. Rapid advancements in the medical and scientific fields have resulted in the provision of basic sanitation services in both urban and rural areas. One of the first cities in the United States to get piped drinking water was Philadelphia. In 1801, drinking water began to flow via the mains of the Philadelphia Water Department. Interestingly, it was a major step by the public health protection system to connect the spread of diseases with centralized water systems [5,6]. The use of different water treatment and purification techniques for domestic wastewater (DWW), such as filtration, well-maintained distribution systems and disinfectants under the aegis of Centre for Disease Control and

Prevention (CDC), are some of the best practices of the 20th century (under the umbrella of infectious disease control).

Domestic wastewater (DWW) is the wastewater derived from household activities such as washing clothes and utensils; bathing; cleaning one's hands, home and vehicles; defecation; and micturition. The DWW can be subcategorized as yellow- (containing urine), brown- (containing feces plus flushed water), black- (containing urine, feces, bacterial activity) and greywater (containing water from the kitchen, laundry, shower and handwashing) (Figure 1).

DWW contains millions of intestinal bacteria and a minority other organisms which further lead to threats to the population. Laundry WW, which is rich in detergents, phosphates and nitrates, causes foam formation and endangers the aquatic organisms of the freshwater ecosystem through eutrophication. Hence, the purification of DWW is crucial for the sustainability of water bodies and aquatic life [7].

As per the global database, there are more than fifty-eight thousand WWT plants in the world. Among these, there are more than sixteen thousand in the United States and eighteen thousand in Europe. In US alone, 62.5 billion gallons of wastewater (on an average 50 to 70 gallons is produced per person per day) is treated every day. The establishment of more sewage treatment plants (STPs) would serve as a solution the problem. The strategies for removal of pollutants from wastewater include conventional methods (sand filtration, coagulation/flocculation, precipitation, biodegradation, adsorption using activated charcoal), established methods (evaporation, oxidation, incineration, solvent extraction, membrane separation, membrane bioreactors, electrochemical treatment, ion exchange) and non-conventional methods (advanced oxidation, biosorption, bio/nanofiltration, biomass, adsorption onto nonconventional solids).

Treatment of sullage/greywater and conversion of sludge into various less harmful by-products can be performed by conventional processes. The conventional methods can be divided into preliminary, primary, secondary and advanced treatment processes. The basic objective of WWT is (i) removal of the biodegradable organic substances; (ii) removal of various nutrients, such as phosphates; (iii) destruction of pathogens; and (iv) prevention of water pollution to safeguard aquatic organisms. However, maintenance and monitoring, emerging contaminants, low efficiency and sludge treatment and disposal are the major limitations, as they increase the total cost of WWT.

Besides the conventional waste in sewage, non-conventional waste (emerging contaminants), such as industrial chemicals, pesticides, pharmaceuticals and personal care products, is increasing day by day [8]. Effective removal of these emerging contaminants can be achieved through adsorption regimes [1]. Removal of antibiotics is necessary, as they may destroy the existing microbial populations of natural water bodies. Photochemical destruction of antibiotics such as penicillin G (PENG) is a green and efficient advanced oxidation process that can be applied to treat wastewater containing non degradable antibiotics [9]. Nanoparticles can also be used to trap and remove hazardous contaminants from wastewater systems. Magnetic-MXene has been established as an efficient nanoparticle-based WWT system, but further research is needed to increase the scale-up efficiency of all such methods [10]. Wastewater from different sources contain heavy metal (HM) contaminants such as mercury (Hg), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu) and lead (Pb) that are non-degradable and lead to biomagnification. These HM components can be effectively removed from waterflow by metal–organic frameworks (MOFs) or porous coordination polymers (PCPs) by their highly organized structures with different organic groups. Although they can effectively trap and remove all HM components, they are specifically used to remove Cd^{II} from aqueous media [11].

Thus, apart from conventional strategies, a blend of conventional and modern and innovative strategies can effectively mitigate the problem of WWT for sustainability in WWT regimes [8,12].

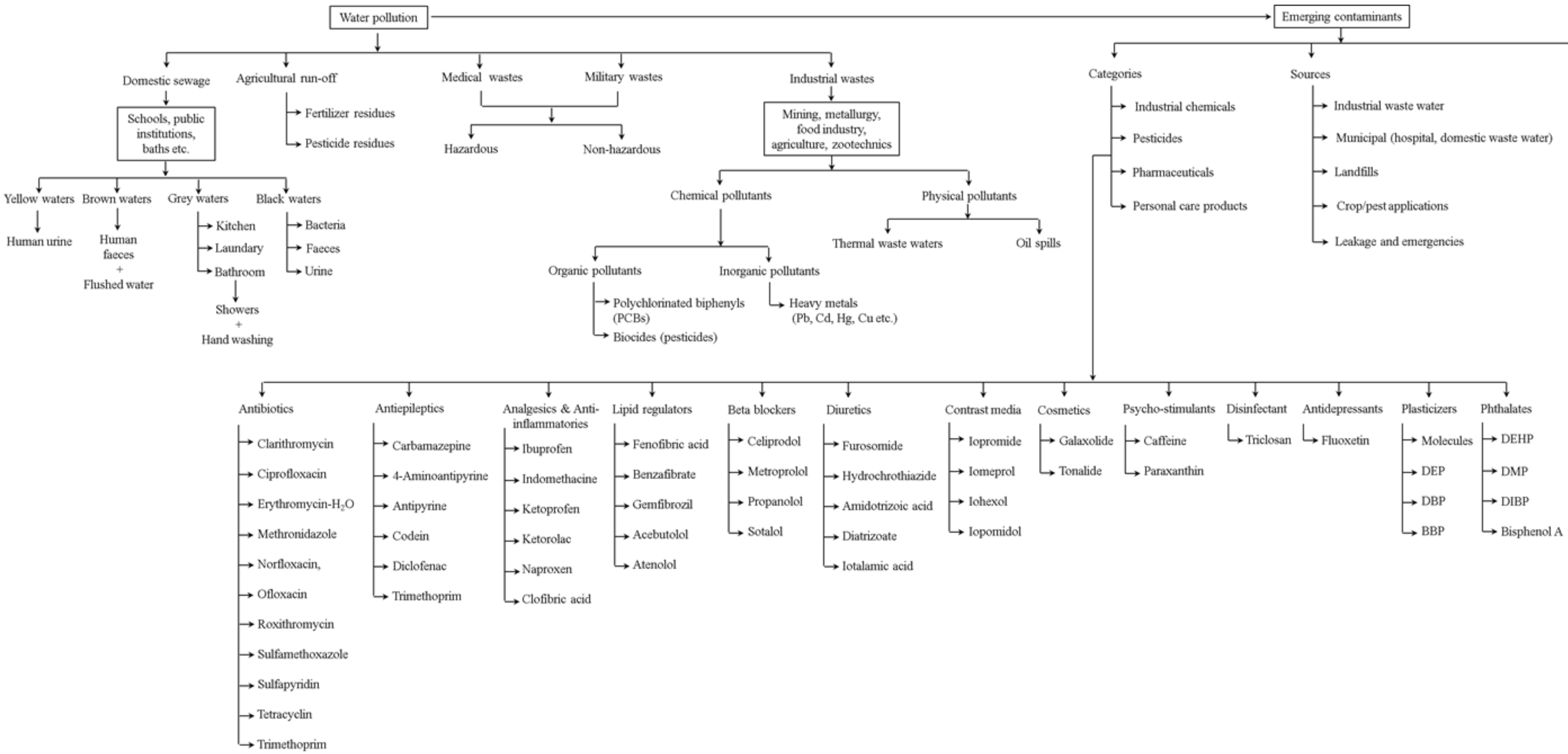

Figure 1. Water pollution: sources and emerging contaminants.

2. Water Contaminants

Water gets frequently contaminated from various sources, as shown in Figure 1. Industrial, agricultural and domestic wastes severely contaminate water. Contaminated drinking water may contain several kinds of pathogens, such as bacteria, viruses and protozoa, which are potential threats to public health [13]. Water supplied under indirect potable reuse (IPR) projects is most likely contaminated by viruses. Although a large number of particles may be present in municipal waste water (MWW) and most of them are susceptible to chlorine inactivation, the presence of excess particles in contaminated water needs careful management [14]. MWW effluents infected by viruses may further cause serious human diseases, such as gastroenteritis and hepatitis. A proper analysis in the laboratory is required to monitor the presence and control of viruses. Waste produced by military facilities is more or less similar to the waste produced by the civilian residential communities or commercial facilities, and the disposal of the excreta and other organic wastes is crucial for effective WWT.

2.1. Characterization of Wastewater (WW)

Wastewater is any water whose quality has been degraded in terms of physical, chemical and biological composition by anthropogenic activity. This water possesses a wide range of contaminants at various concentrations. Routinely testing and monitoring the water quality is mandatory for eradicating the potential hazards. The majority of wastewater contains 99.9% water with relatively small amounts of suspended and dissolved organic and inorganic contaminants.

2.1.1. Total Dissolved Solids (TDS)

Total dissolved solids (TDS) in water are some organic and inorganic materials which include minerals and ions that remain dissolved in water even after the normal filtration process, and they are larger than 2 microns. The amount of TDS is increasing due to the use of water softeners. TDS content varies in MWW effluent content from 150 to 380 $mg \cdot L^{-1}$ [15]. The presence of chloride, sulfate or sodium—major ions—minimally affects the hardness, but increases the TDS value by up to 75, 44 or 74 mg L^{-1}, respectively, and does affect the taste and acceptability of drinking water [16]. The TDS level recommended by WHO is 300 ppm, whereas according to the Bureau of Indian Standards (BIS), TDS levels may go up to 500 ppm. TDS levels ranging from 350–500 mg L^{-1} are fairly acceptable for drinking water, and the maximum permissible level for TDS in wastewater is 2000 mg L^{-1}.

2.1.2. Dissolved Organic Carbon (DOC)

Dissolved organic carbon (DOC) is the dissolved carbon that supports the growth of microorganisms in water. It represents the carbon compounds present in water that can pass through filters with pore sizes ranging from 0.22 to 0.7 μm [17]. DOC acts as a source of nutrients for the growth of microorganisms. Natural and synthetic organic matter and soluble microbial products (SMP) are present in MWW effluents as DOC [16,18]. Diverse chemicals that originate from factories, households and other places are pesticides, personal care products, surfactants and steroidal hormones that are excreted by humans contaminate the water and contribute to the DOC. Linear alkyl benzene sulfonates (LAS) are anionic components of the detergents and are commonly present in raw wastewater with other anionic surfactants, which are used in commercial and domestic detergent products and are harmful to human population [19,20]. Accumulation of nutrients such as nitrogen and phosphorus induces bacterial growth and the growth of aquatic plants and algae (cultural eutrophication) [21]. Thus, WWT is necessary to remove these nutrients to prevent the unwanted growth of harmful microorganisms in water.

2.1.3. Microorganisms

Various aerobic and anaerobic microorganisms remain suspended in the DWW. These microorganisms change the properties of water, and some of them are harmful to the human population [7]. Facultative bacteria in wastewater use free oxygen as an electron acceptor and thereby carry out the oxidation of organic matter to more stable products. In putrefaction, microorganisms are not able to directly oxidize the organic matter to their final products, so they convert it into simpler intermediates. These intermediate products are used to study biological cycles. Different gases, including hydrogen sulfide, methane, etc., are also released in this process, which produce a foul odor. The concentration of organic matter in wastewater can be estimated by the amount of oxygen needed for the oxidation process. Some of the basic parameters that express the oxygen demand of organic waste are:

(A) Dissolved oxygen demand (DOD)

The amount of oxygen present in a dissolved state in a water sample is known as the DO. DO is an indicator of the water quality, and it is essential to ensure that the DO concentration of the effluent be at least 4 mg L^{-1} after its discharge through the treatment plant. Below this range, it adversely affects aquatic organisms [22]. The DO content of the effluents after WWT processes reflects the efficiency of the biological treatment phase.

(B) Biochemical oxygen demand (BOD)

BOD is considered as the amount of oxygen that is consumed or required by microorganisms to decompose the organic matter present in the water sample. A BOD test can be used to measure the extent of pollution of both domestic and industrial WW and to evaluate the purification capacity of receiving water bodies. An incubation period of 5 days at 20 °C is used to measure the BOD, and the measurement is referred to as the BOD5. A high BOD5 denotes the presence of much organic matter in the wastewater or any water sample [23]. Drinking water, clean water and polluted water have BODs in the ranges of 1–2, 3–5 and 6–9 ppm respectively.

(C) Chemical oxygen demand (COD)

It indicates the amount of oxygen required to degrade the organic matter in a water sample (mg L^{-1} or g m^{-3}). The COD value is directly proportional to the oxidizable organic matter present in a water sample, which is inversely proportional to the dissolved oxygen (DO) value. COD is higher in water sources contaminated with food waste from bottles, cans, emulsified oils, etc. Pollutants that increase COD are mostly water-soluble and easily spread from storm water to waterways. The results of COD measurements are obtained within a short period of few hours [24], but the COD does not reveal information related to the proportional quantity of biodegradable organic matter.

Domestic wastewater contains a large number of proteins and sugars, and also some fiber. Protein, sugar and fiber constitute 12.38%, 10.65% and 20.64% of the total organic carbon (TOC). The soluble fraction of degradable bioproducts constitutes 30% of the total COD of DWW. DWW also contains various secondary nutrients, such as nitrogen and phosphorus compounds, that also contribute to increasing the COD value [25,26]. Conventional WWT focuses on removing the organic and suspended nutrients to reduce the COD of DWW [27]. There are various conventional WWT processes for the removal of soluble and insoluble organic or inorganic components from DWW [25,28]. These are represented in Figure 2 and discussed below.

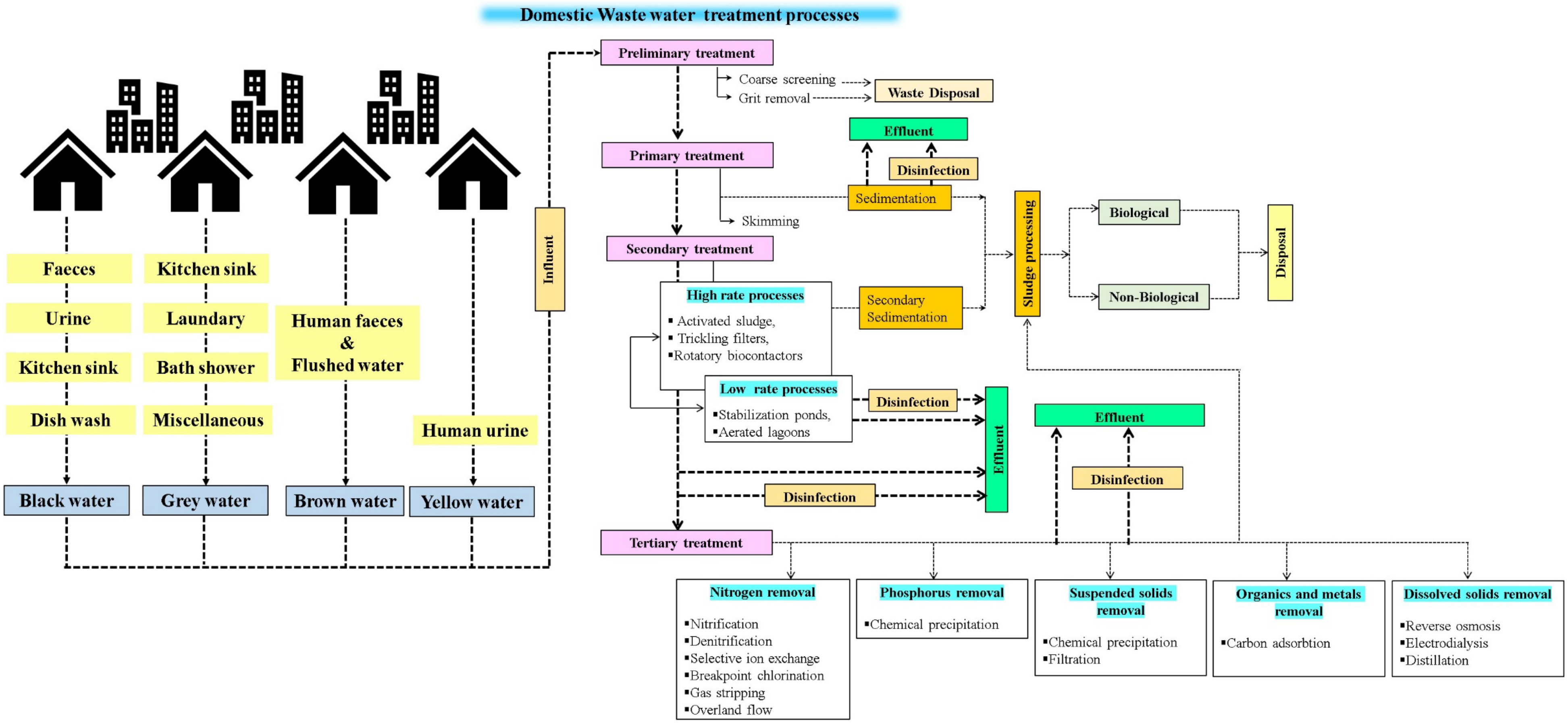

Figure 2. Schematic representation of a general domestic wastewater treatment (WWT) regime.

3. Process of Wastewater Treatment

3.1. Preliminary Treatment Plant

This process removes debris and coarse particles suspended in the wastewater. Unique facilities and equipment are required in this phase to separate rags, grit, foreign objects and other debris. If not done, it becomes difficult to deal with large substances during other subsequent operations. The preliminary treatment plant removes 25% of the organic load and almost all of the non-organic solids. The waste material is removed and disposed of in a landfill. The screening can be classified according to the use of fine and coarse screens. Coarse screens are used in preliminary treatment, whereas fine screens have been deployed as a substitute to sedimentation. Solids are also passed through each channel, so they convert into shredded matter through comminution. Grit chambers are used in a separate system which slows the velocity of water flow in order to remove the inert/inorganic materials [29]. Economically, it prevents the operation problems in channels and pipes and reduces the formation/accumulation of excess sludge [25,28].

3.2. Primary Treatment Plant

The floating materials and settled organic and inorganic matter are removed during this process. Around 60% of grease and oil, 50% of BOD5 and 70% of suspended solids are oxidized at this stage. Some organic nitrogen and phosphorous and HMs are removed from the wastewater during primary sedimentation. The effluent obtained from primary sedimentation is referred to as primary effluent [25].

3.3. Secondary Treatment Plant

During this process, some of the residual solids and colloidal and biodegradable wastes are removed in an aeration tank, in which micro-organisms are exposed to wastewater. Microorganisms degrade it into an inorganic end-product. High-rate processes are the most applicable parts compared to low-rate processes because they maintain the high content of micro-organisms under controlled conditions. Mechanically, it is possible to treat bad water through trickling filters, activated sludge and a rotatory biological contactor [25].

3.4. Tertiary Treatment Plant

This stage of purification involves some extra steps that reduce organics, nutrients, turbidity, nitrogen, phosphorous, HMs, bacteria and viruses. The main purpose of this treatment plant is reuse or recycling of wastewater so that it can be used further for irrigation, etc. Purified water is then allowed to meet with water reservoirs.

3.5. Disinfection

At this stage of the water purification system, the final treatment is performed by using the chemical and physical methods. Chlorine and its derivatives are used as disinfectants during this stage. This treatment (chlorine treatment) varies according to the type of wastewater and other elements, such as pH, organic content and the type of effluent received. Other treatments, such as ozone or UV treatment, can be performed as a requirement for irrigation, and the reclaimed wastewater can then be used in urban areas.

4. Process of Water Purification

To fulfill the purpose of the conventional WWT processes, various types of wastewater purification systems have been developed. Widely used purification systems are as follows:

4.1. Preliminary Treatment

Preliminary or pre-treatment is performed to protect the WWT plant from physical damage or clogging problems. All suspended solid garbage, fecal matter, oil, grease and grit are removed from the wastewater flow. This includes the process of coagulation and sedimentation [30]. Sedimentation is carried out in large tanks called clarifiers, and the process is also called the clarification process. Pre-treated water is subjected to coagulation and flocculation for further removal of suspended materials [31].

4.2. Primary Treatment

After the removal of the heavy suspended materials from wastewater, primary treatment processes are followed. Primary treatment includes coagulation, flocculation and precipitation technique to remove suspended organic and inorganic substances from the water.

(a) Coagulation and flocculation

Coagulation involves the addition of various aluminum or ferric compounds, such as ferric chloride, aluminum sulphate and sodium aluminate, into the water as coagulants. They are hydrolyzed in water and produce metal ions covered with positive charges. They neutralize suspended charged particles. Separation of coagulants can be performed in a clarifier or settling tank. Filtration techniques (microfiltration) are carried out for further clarification [32]. In settling tanks, suspended metal ions and soluble organic ions settle to the bottom. Sediment is removed as sludge, and the remaining water undergoes the filtration process. Natural organic matter can be withdrawn in large amounts, but coagulation does not kill the pathogens completely [32]. Pathogens remain suspended in the treated water and thus are not used for drinking. Coagulants are used for both filtration and flocculation purposes.

Flocculation brings particles together which move with different velocities through the wastewater tank. Materials used as coagulants improve the attachment of moving, small, suspended particles which are retained as large flocs. Coagulation and flocculation substances are typically administered downstream of the quick mix, near the midpoint, or at the end of a conventional flocculation processes. The addition of flocculant upstream of the filtering process and rapid mixing with water allow flocculation of suspended particles [32,33]. Rapid mixing has a primary objective of making a uniform distribution of flocculants in the system. The output depends on the characteristics of the compound used for the coagulation and flocculation process. However, dispersion activity can be determined by the detention time factor. Rapid mixing in dispersion-oriented basins can be carried out by mechanical mixers, static mixers or hydraulic jet dispersion. The design of the flocculation steps generally depends on the floc characteristics which are desired for downstream clarification and filtration [33].

(b) Precipitation

During precipitation processes of WWT, various chemicals are used that can react with HMs to generate insoluble precipitates. Precipitates are further separated from the water by the process of filtration or sedimentation [34]. Metal ions can be removed from wastewater by precipitation as hydroxide compounds at elevated pH. They may also be separated by sulfide precipitation [35]. A precipitation technique is usually performed to remove the phosphorus compounds, metal ions and radioactive elements dissolved in WW. Hydroxide treatment is the most commonly used method in the precipitation process as a cost-effective approach. The automatic pH control of the hydroxide treatment method makes it the simplest technique for precipitation. Calcium and sodium hydroxide compounds are generally used as precipitants [36].

Hydroxide precipitation produces relatively low-density sludge in a huge volume, which is its major disadvantage. A large volume of low-density sludge creates dewatering and disposal problems. Hence, sulfide precipitation is an alternative to hydroxide precipitation. A large amount of metal can be removed as metal sulfides by this technique, even at a low pH. Metal-sulfide sludges have better dewatering capacities than metal hydroxide sludges produced in hydroxide precipitation. This provides a major advantage to the sulfide precipitation technique. Sulfide precipitation produces toxic H_2S fumes and sulfide colloidal precipitates, which is a major disadvantage of this technique [34,36,37].

(c) Chemical precipitation

Chemical precipitation is a proven technology for the removal of inorganic, HMs, fats, oils and grease from wastewater. It captures ions during the processing and can sweep out various ions from the wastewater to improve its quality. Different stages are performed to precipitate the HM, phosphorous, fat, oil and grease suspended in wastewater, and water softening will be induced. Divalent cations are removed through the addition of calcium oxide in hard water to change its properties. To neutralize the emulsification formed by an oily substance in solution, it is necessary to break their hydrophobic interactions [37]. Polymers are used to disrupt the interactions between large oily particles. Phosphorous removal is an important step to decreasing the concentration of polluted debris found in water bodies and can be performed by using metal ions. The authors of [38] deciphered that phosphate can be effectively removed from wastewater streams as crystallizing struvite ($MgNH_4PO_4{\cdot}6H_2O$) by using a dense suspension of low-grade magnesium oxide. Ying and Fang reported that dipropyl dithiophosphate can successfully remove 99.9% of the suspended copper, lead, cadmium and mercury with 200 mg L^{-1} concentrated wastewater and reduce their concentrations to 1, 0.1, 0.5 and 0.05 mg L^{-1}, respectively, in effluent water [39]. The advantage of this precipitation technique is that its effectiveness is independent of the pH value and is not influenced by the coexistence of other HMs in the wastewater sample.

Like the clarification and coagulation process, a typical softening process involves either sedimentation basins or conventional flocculation. The precipitation process is followed by pH adjustment (re-carbonation) and filtration. A high concentration of carbon dioxide will increase the doses of lime and other chemical solids. Before the softening, aeration is performed to reduce the carbon dioxide concentration. Adjustment of pH has to be performed before filtration and for chemical treatment in the lime softening system, which includes lime-singly, lime-soda, ash and caustic soda [37]. Achieving the best quality water with low non-carbonaceous substances can be performed by lime treatment. Caustic lime soda is used rarely in potable water treatment because it is a cost-effective method but has an equivalent property of removing organic particles. The authors of [40] reported the effective use of lime in combination with fly ash, and CO_2 gas also effectively removed copper, lead, zinc and chromium, which significantly improved the quality of sedimentation sludge and effluent water. The advantage of this technique is that its precipitate hardens or stabilizes naturally, and reduces disposal measures of sludge and hence the cost.

4.3. Secondary Treatment

Colloidal solids and biodegradable waste material remaining in wastewater are separated during this process. This process includes adsorption, biodegradation and filtration.

(a) Adsorption

Solid substances can attract molecules of solutes from solution as they come in contact with their surfaces. The solid materials used to attract the dissolved substances in a solution are called adsorbents, and the adsorbed molecules are collectively called adsorbates [1]. Adsorption in wastewater management refers to the process where solutes in the water sample accumulate over the absorbent surface and form a film of absorbate molecules [41]. Due to its low cost and easy set-up, the availability of adsorbents and the reliability of the technique, it is widely used to remove the toxic metal ions from DWW effluents. Active carbon is used as an absorbent to remove excess pollutants which are polar. Granular activated carbon and powdered activated carbon are two forms of the same material and are mostly used to purify water effluents. The only difference is their particle size according to US standard sieve size. Their equal molecular weights justify that they have the same characteristics and same function. The granular and powdered forms have different contaminant-absorbing abilities. Thus, there is a functional difference between these two forms of activated carbon. Granular activated carbon can be installed in the mixed bed, and it efficiently sticks to contaminants and can be continuously replaced with regenerated granular carbon. A wide range of cost-effective active carbon sorbents are produced from eucalyptus bark, poultry litter-based sources, rubber wood sawdust, coconut shell, sawdust of Indian rosewood, rice husk and other biotic and abiotic sources [42–46]. Activated carbon produced from different sources can efficiently remove Pb^{2+}, Cr^{2+}, Co^{2+}, Ni^{2+}, Cd^{2+}, Cu^{2+} and Cr^{6+} from aqueous solutions [41]. The adsorption technique is used for all treatment purposes, from the treatment of home to industrial effluent to the treatment of aquatic water. Rather than activated carbon, several other materials, such as clay minerals, zeolites, agricultural waste, industrial by-products, biomass and polymeric materials, which possess high adsorption capacity for the target contaminants, can be used [41].

(b) Filtration

A filtration technique can remove suspended particles and improve treatment efficiency. Filters used in this technique have variable pore sizes. Lower pore sizes keep more particles in the filter and allow easy water passage. This method is mostly used for the treatment of groundwater, and it is used to remove floc created by coagulation processes during wastewater treatment. Slow sand filtration techniques involve bacteria forming a biofilm layer on a contaminated sand surface and turn wastewater into safe water by removing impurities [47]. Rapid filtration almost removes all of the contaminants from water. The filtration rate is high, but it is not a suitable approach to getting rid of bacteria and viruses. Disinfectant treatment is still more successful, even with a low concentration of chlorine.

(c) Biological process

The biological wastewater treatment processes can be categorized depending upon the dominant primary metabolism pathway found in the microbial population active in the treatment system. Regarding the availability of oxygen and its utilization, biological treatments are divided into aerobic, anaerobic and anoxic processes. The aerobic processes of biological treatment use molecular oxygen and thus consist of microorganisms that perform aerobic respiration and produce more solids as cell mass. The anaerobic wastewater treatment process does not use free or combined oxygen molecules and generates their energy from methanogenesis or reducing sulphate compounds. They produce sulphate and biogas methane as by-products. The anoxic wastewater treatment process does not use free molecular oxygen during respiration, but it uses oxygen combined from inorganic material such as nitrate present in the wastewater. The process is used to remove nitrogen from waste by denitrification [25].

(d) Trickling filter

Trickling filtration is a wastewater purification process also called bacterial bed filtration [48]. The fixed media used in this process are made up of coke, polyurethane foam, rocks, gravel, sphagnum peat moss, ceramic and slag or plastic, and is porous in nature. Settled wastewater flow is passed through the filters, which allows bacteria to colonize on the media bed. Bacterial growth produces a microbial slime layer on the media bed through biofilm formation. The process is also named trickling biofiltering. The film provides a barrier to prevent the flow of larger particles. Larger organisms get stuck on the filter above the bacterial film. This process is called grazing. Grazing process is necessary to keep the biofilm active for a long period. Organic materials in sewage water are distributed throughout the surface of the fixed medium, and the soluble dissolved organic materials are absorbed by bacteria. Due to unchecked and uncontrolled bacterial growth, or sometimes due to overgrowth, bacteria clog the medium, which reduces the efficiency of the biofilter. This can be prevented by the shearing of biomass through wastewater flow. The available surface area of the medium used in the filtration gives an estimate of possible area for bacterial growth and thus biomass. The major components of a trickling filter are shown in Figure 3.

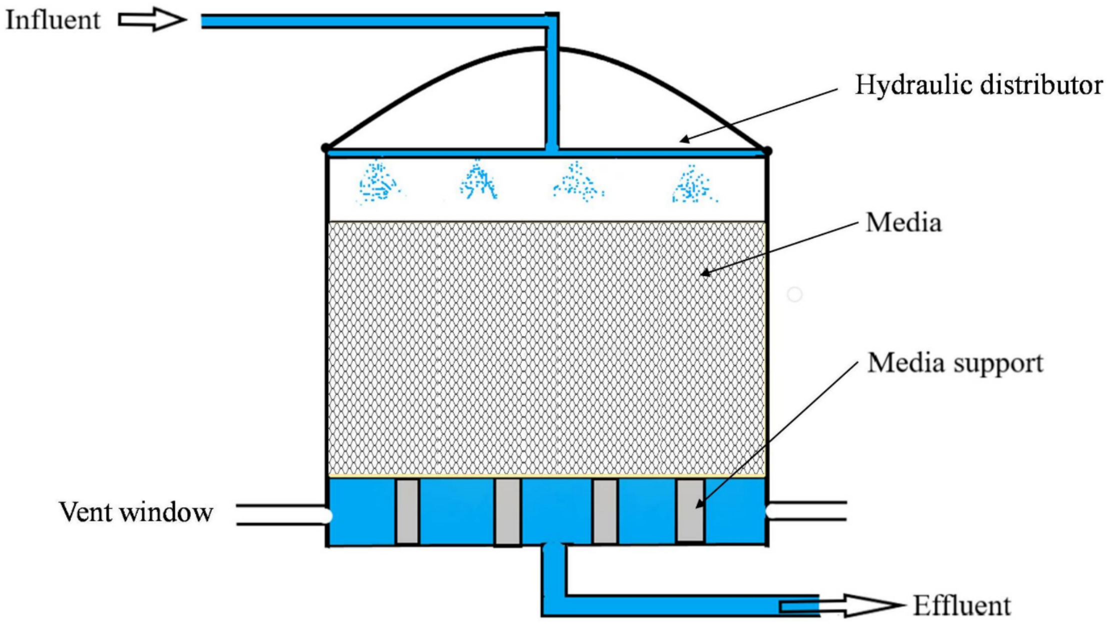

Figure 3. Major components of a trickling filter.

Biofilm thickness varies in different trickling filters and also depends on the medium used as a filter. The gelatinous matrix used as a medium allows the growth of bacteria, ciliates, protozoa and various worms, to develop its own microflora. Biofilm thickness is 1 mm or less for various matrixes. Aerobic and anaerobic zones observed in the biofilm support both oxidative and reductive biological processes. Aerobic bacterial respiration is maintained during the trickling filter by splashing, diffusion or forced airflow in the chamber [49].

The rate and efficiency of trickling filter depend upon the loading rate of wastewater, and the surface area, shape, size, depth and porosity of the media. For different waste sample types, different filtering processes are performed. Types of trickling filtration: (i) Standard-rate trickling filtering: This type of filtering has a low loading rate and does not include the recirculation process. The effluent of this process maintains BOD at <30%. (ii) High-rate trickling filtering: This technique is more efficient than the standard-rate filtering due to the use of the recirculation process. It has a high effluent rate and a lower BOD as some fraction of the primary effluent added with the primary influent. (iii) Alternating double filtration: It is another type of tickling filtration process where two filters are alternately used as the first filter. The first filter gets inputs with high organic matter, which allows growth of biofilms on it. The second filter gets the effluent of the primary filtration, which will contain less organic material and allow low bacterial growth. To keep the biofilms on the filters even, after a certain period of time the direction of water flow is changed. The second filter starts receiving organic-material-rich influent, which induces bacterial growth. As the first filter starts receiving less dissolved organic matter, the biofilm will start degrading, and thus the biofilm flocks are maintained for optimum function.

(e) Biomass on filter

Bactria form the majority of the population that degrades the soluble organic matter suspended in wastewater. Nitrifying bacteria convert the suspended ammonia into nitrates. Thus, effluent water remains well nitrified. Members of the fungal and algal populations remain on the biofilm formed by bacteria. Algae produce O_2, which serves the upper layer of biofilm that consists of aerobic bacterial flocks and helps with keeping them active. The fungal species found mainly stabilize and degrade the organic waste suspended in the wastewater. Some amoeboid protozoa also colonize the biofilm. They feed on the bacterial population and keep the film dynamic and active. Other than bacteria, fungi, algae and protozoa in the biofilms allow the growth of other organisms, such as rotifers, insect larva and snails. All of them help maintain the dynamic nature of the biofilm.

(f) Design and implementation

1. Pre-treatment of the wastewater
   Biological filtration or a trickling filter is suitable for the secondary treatment of primary effluent. Pre-treatment of the wastewater is necessary to remove the clogging material from the waste before starting the process.
2. Distribution system
   Even distribution of settled sewage on the filter is necessary to maintain equal growth conditions for the biofilm-forming bacteria. To maintain the distribution, a piece of dosage equipment is necessary.
3. Filter bed and types
   Circular filter beds are preferred over other shapes to increase the surface area of the media. The media used in this process as a filter should be chemically inert and must support the biofilm.
4. Dimensions of the filter
   Granular intact components should be used as filter media, and the material chosen must provide a suitable environment for the growth of a bacterial biofilm.
5. Effluent system
   Effluent collecting channels must be large enough to efficiently drain a large volume of purified water to support the maximum flow rate.
6. Ventilation
   A well-organized ventilation system is necessary to keep the aerobic biofilm layer functional. Sufficient opening at the base of the filter provides a good ventilation system to the plant. Air inlets are also useful for aeration, and they may be included in the chamber at various positions.

Advantages of trickling filtration

i. It is a simple filtration process that uses microorganisms to filter out organic soluble impurities. As no chemicals are used, it is safe for the biotic ecosystem.
ii. A rapid reduction in the level of BOD is observed in the effluent water, which depicts a good-quality treatment.
iii. It is a simple, reliable and effective process for purifying domestic wastewater.
iv. The low consumption of energy and durability of the filter make it a cost-effective technique.
v. No highly trained and skilled operator is needed to run the process. It is a suitable filtration process for small or medium-sized community use [49].

Disadvantages of trickling filtration

i. The process on its own is not sufficient for the purification of domestic wastewater. Pre- and post-purification systems are required.
ii. The biofilm thickness must be under control. Increased thickness of biomass on filter impairs the process of aerobic respiration and thus reduces the efficiency of trickling filtration.
iii. Regular attention is required to prevent the clogging problem [49].

(g) Biosorption

Biosorption is the process of removing metal ions from an aqueous solution by their passive binding to biotic organisms. The interaction between the metal ion and biomass depends upon ionic properties of the cell coating of the biotic organisms. It largely depends on the ionic composition of the functional groups present on the surface [50]. Microbes such as bacteria and algae contain lipids, polysaccharides and glycoproteins on the cell surface, which possess amino, carboxyl, sulphate and hydroxyl groups. The fungal cell wall contains chitin, amine, sulphate, thiol, imidazole, hydroxyl and phosphate functional groups [50,51]. Metals in wastewater undergo complexation, precipitation and ion exchange with these functional groups present in the aquatic biomass. Complexation is the formation of a polyatomic molecule, and chelation is the formation of a ringed structure between the metal ion and an organic molecule with over two functional groups [50]. As the process depends upon the charged particles on the biotic organisms, biosorption is affected by the solution's pH and the temperature and presence of biomass in the solution. Biosorption is a simple, cost-effective procedure to efficiently remove the metal ions suspended in the wastewater. It produces minimum biological and toxic chemical sludge and allows easy metal recovery. These are the advantages of the biosorption process [50,52].

(h) Activated sludge processing (ASP)

Activated sludge processing is a conventional wastewater treatment process where an aeration basin wastewater is aerated so that micro-organisms metabolize the suspended organic matter. The organic matter is converted, and energy is used to form new cells. These newly formed cells are removed as flocculent sludge from the wastewater stream. A fraction of this settled biomass is called activated sludge and transferred to the aeration tank, and the remaining is released as waste or excess sludge [53].

The components of ASP are:

i. Reactor: The reactor is a kind of tank for mixing and aeration of the wastewater, and it is also known as the aeration tank.
ii. Activated sludge (AS): The microbial biomass present in the reactor is abbreviated as AS. Bacteria, fungi and other unicellular or multicellular organisms comprise the biomass. The suspension of these organisms in the AS is called the mixed liquor.
iii. Aeration and mixing system: Aeration and mixing of wastewater with AS are essential to maintain the air concentration and microbial population in the newly added water in the tank. Different techniques, such as diffused air and surface aeration, are used for this purpose.
iv. Returned sludge: The fraction of AS settled in the sedimentation tank is added back to the reactor to maintain the basal microbial concentration in the reactor tank for effective purification [53]. Components of ASP and its functioning are represented in Figure 4.

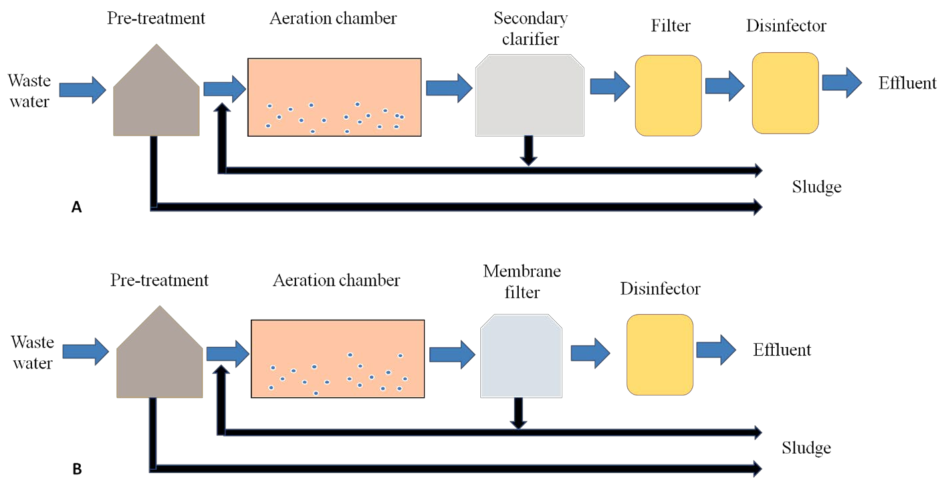

Figure 4. Flowchart of (**A**) the activated sludge process and (**B**) membrane bioreactor (MBR) technology.

Advantages of ASP

i. Installation is cheaper than it is for other techniques.
ii. Does not require large an area to install and produces good effluent quality.
iii. Low foulant and lower pest accumulation; thus, it is safer to use [30].

Disadvantages of ASP

i. The hydraulic retention time for ASP is longer, and thus, it takes as much as 5 days to achieve the desired level of treatment. It is a much slower process than other conventional wastewater treatment techniques.
ii. Operation costs are higher than those of the others.
iii. A sudden change in the amount or in the character of sewage flow may disrupt the process.
iv. It generates a high sludge volume and fast disposition. Its sludge retention time is low, which increases the overall operational cost.
v. As the process requires activated sludge recycling, continuous and skilled supervision is necessary to keep the system active [30].

(i) Membrane bioreactors (MBRs)

The MBR is a WWT system which combines both biological (activated sludge process) and membrane filtration (UF, MF, RO) to purify wastewater flows. It is derived from the activated sludge process of wastewater treatment, but the secondary clarifier is replaced with membrane filters. Membranes are used to separate virus, colloids, bacteria and other solids developed by biological processes [54]. It is superior to ASP, but it has a few disadvantages. The mechanism of MBRs is presented in Figure 4.

Advantages of MBRs

i. The membrane used in an MBR can filter all pathogenic microorganisms, solids and biological waste suspended in the domestic and industrial wastewater.
ii. The MBR membrane has a small pore size of <0.5 μm, which produces clear effluent water. It can remove 99.99% of total coliforms in water, and clear water is produced as effluent for direct potential reuse. As the secondary clarifier of ASP is replaced in MBR by the membrane, the footprint required in ASP is reduced.
iii. MBR can efficiently purify huge volumes of domestic water continuously. Thus, it is more efficient than ASP.
iv. No chemical is used in the process, and an MBR operates at higher biomass concentrations with lower sludge production thus reduces sludge disposal costs [55,56].

Disadvantages of MBRs

i. Any MBR has high operational costs, and it has high complexity, which creates a drawback for this process.
ii. Due to deposition of organic and inorganic materials on the membrane, there is fouling of the membrane. The physicochemical interactions between the MBR's membrane and deposited components reduce the membrane efficiency, which creates a problem and must be controlled. Membrane fouling reduces the membrane's lifetime. Replacement of the membrane is costly [56].

4.4. Tertiary Treatment

This process is performed to remove the suspended materials after the primary and secondary treatment processes. Techniques include membrane filtration and oxidation techniques to make wastewater reusable. As per "Water Conservation and Wastewater Treatment in BRICS Nations, 2020", it is an additional stage of treatment for a biologically treated effluent which is specially designed to remove nutrients left after the secondary treatment, such as phosphorus and nitrogen.

4.4.1. Ion Exchange

Ion exchange wastewater treatment rests on the principle of exchange of ions between an electrolytic solution and a solid phase. Exchange of the ions does not lead any structural changes to the solid phase. It is the most frequently used technique to remove HMs suspended in the wastewater. Ion-exchange resins of various strengths are used to separate the metal ions from wastewater samples. A weakly basic, microporous-type resin with macro-pores was found to be efficient for chromium removal, but for zinc removal, a strongly acidic cation-exchanger resin was found to be more effective [36,57]. Natural cost-effective minerals such as zeolite are also used frequently for the removal of HMs from wastewater samples [36]. The advantage of this technique is that the metals can be selectively recovered from the wastewater, thereby producing a small volume of sludge that can be easily disposed of. The major disadvantage is that the optimum metal concentration must be in the range of 10–100 mg L^{-1} [36]. It cannot be effectively used if the metal concentration ends up lower or higher in concentration than the optimum for this process.

4.4.2. Membrane Filtration

Membrane filtration is another well recognized method for wastewater treatment which is effectively used to produce better-quality water for human use. Nowadays, it is often used to purify wastewater streams contaminated with diverse types of pollutants of different origins. Various membrane-filtration techniques are used for industrial effluent purification processes. These include (a) microfiltration (MF), (b) ultrafiltration (UF), (c) nanofiltration (NF), (d) reverse osmosis (RO), (e) membrane bioreactors (MBRs) and electrodialysis reversal desalination (EDR).

(a) Microfiltration

Microfiltration is the process of physical separation for the removal of solids and bacteria suspended in wastewater by a membrane. The process uses the membrane with small pores of 0.1–10 microns in size [58]. As it is a physical process, soluble materials cannot be separated by this method. Algae, protozoa, bacteria and sediment particles suspended in water can be easily segregated by this technique [59]. MF cannot prevent the passage of viruses, as they are smaller than the pores of membranes used in this process. MF is frequently used in MWT, as it can prevent the passage of pathogenic bacteria and protozoa and is also more cost-effective than other membrane-filtration techniques. The authors of [60,61] used a coal-based microfiltration carbon membrane to reduce oil in the effluents, and a sharp reduction of 97% was observed in the filtrate wastewater, which signifies the role of nanofiltration in purifying insoluble substances from water bodies [62].

(b) Ultrafiltration

It is a kind of membrane filtration process where hydrostatic force is used to force water to pass through a semi-permeable membrane with 0.001–0.1 μm pores. Solids of high molecular weight in wastewater are retained in the membrane, and low-molecular-weight molecules pass through it. It creates a pressure-driven barrier for HMs, bacteria, heavy macromolecules and solids suspended in wastewater samples. The membrane used in UF can efficiently separate molecules of 20–150 kilodaltons [58]. This method does not use any chemicals and can remove 90–100% of suspended material from wastewater. As the membranes used in this filtration process are costly, their use is limited. It is mostly used to remove proteins from various industrial effluents. Li et al. effectively used polyvinylidene fluoride filters modified with aluminum nanoparticles to purify oily wastewater and were able to remove 98% of suspended organic carbon from the effluent [63]. Barakat and Schmidt (2010) efficiently removed Ni (II), Cu (II) and Cr (III) from synthetic wastewater by using carboxy-methylcellulose complexation UF [64]. Jiang et al. performed conventional UF and was able to remove suspended dye and salt from textile wastewater samples [65]. Ren et al. used titanium oxide (TiO_2)-modified polyvinylidene fluoride (PVDF) UF membrane to remove antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARGs) from biological wastewater [66]. The process successfully retains ARB and ARB, and after UV illumination induces complete degradation of ARGs. Thus, ultrafiltration can be used effectively for removing all kinds of the suspended molecules with slight modifications or in combination with other conventional wastewater management techniques.

(c) Nanofiltration

Nanofiltration is another membrane-filtration technique and is considered as being a compromise between UF and RO. The pore size of NF membranes is between 1 and 10 nm. These are slightly smaller than those of the filters used in UF but larger than those used in RO. NF allows smaller monovalent ions through the pores of the membranes, but it prevents the passage the divalent cations. NF is generally used for the purposes of water softening and removal of bacteria and protein. NF is helpful during softening, as it can retain calcium and magnesium ions and allows the passage of few monovalent ions [60]. NF is also able to process a large volume of water continuously. However, NF is not used much, as the pore size is limited and the combination of RO and UF can efficiently remove more impurities and can remove the need for NF.

(d) Reverse osmosis

Reverse osmosis is a water purification process that uses suitable partially permeable membranes. In RO, a force is applied to overcome the osmotic pressure (OP). OP is generated due to the differences in the chemical potential in the solvent. Reverse osmosis is a pressure-driven membrane process in which water passes through a membrane while the pollutant metal ions are retained. RO removes dissolved solids, particularly metal ions and various colloidal matter from inorganic solutions. RO can also effectively remove the chemical species such as nitrate and color substances, and biotic-factor-like bacteria, from water. The process can be performed at a wide range of pH levels, which makes it a favorable technique for water treatment. Thus, it is useful for both domestic wastewater treatment and producing potable water [60]. RO equipment can be installed for a low price, which makes it a cost-efficient product. The major disadvantage of RO is that it requires continuous power to pump water, and due to the pumping pressure, the membrane may be damaged, which would create problems in the system, and restoration of the filter membrane is costly. Qdais and Moussa reported that RO can remove Cu^{2+} and Cd^{2+} ions from wastewater with 98% and 99% efficiency [67]. A comparative analysis of different membrane filtration processes is shown in Table 1.

Table 1. Properties of different membrane filtration processes.

Characters	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis	References
Molecular weight cut-off (Kilo Dalton)	100–500	20–150	2–20	0.2–2	[59]
Retained compounds	Colloids, TSS turbidity, some protozoan oocysts, cysts, some bacteria and viruses	Macromolecules, proteins, colloids, bacteria, viruses	mono-, di- and oligo-saccharides; polyvalent anions, pigments, sulphates, divalent cations, sodium chloride	Sodium, chloride, glucose, amino acids and sodium chloride	[59,68]
Transmembrane pressure (TMP)	<5 bar	<10 bar	<20 bar	<100 bar	[68]
Retained diameter particles (µm)	10^{-1}–10	10^{-3}–10^{-1}	10^{-3}–10^{-2}	10^{-4}–10^{-3}	[59]
Flow modes	Crossflow, Dead-end	Crossflow, Dead-end	Crossflow	Crossflow	[69]
Membrane	Porous isotropic	Porous asymmetric	Finely porous asymmetric/composite	Nonporous asymmetric/composite	[69]

(e) Membrane bioreactors (MBRs)

Smith et al. introduced MBR technology, which is thought to be a combination of selective membrane process, such as microfiltration/ultrafiltration, and a biological process, for WWT [70]. This integration of biological degradation of pollutants and membrane separation has been recognized as a potent strategy for dealing with wastewater containing salts, minerals and oils (Figure 5). MBRs can be categorized into four classes based on usage: (1) biomass separation membrane bioreactors (BSMBRs), (2) membrane aeration bioreactors (MABRs), (3) extractive membrane bioreactors (EMBRs) and (4) ion-exchange membrane bioreactors (IEMBRs) [70]. Anaerobic membrane bioreactors (AnMBRs) can be trusted for the MWWT, as they effectively remove a wide range of contaminants from wastewater and degrade organics to produce methane-rich biogas for further energy production [71,72].

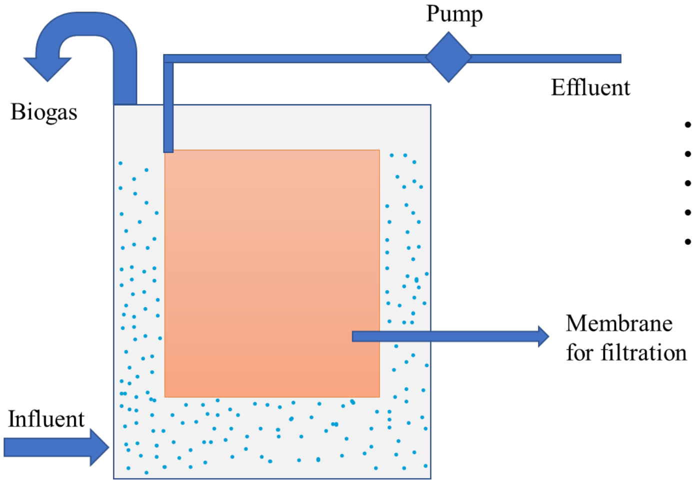

Figure 5. Schematic representation of anaerobic membrane bioreactor (AnMBR) technology.

(f) Anaerobic membrane bioreactors (AnMBRs)

AnMBR is a recently developed WWT system which combines both anaerobic digestion and physical separation methods, such as ultra-filtration or micro-filtration membranes, to separate both organic and inorganic load from wastewater flow [72,73]. Anaerobic digestion of organics produces a large amount of biogas which can be used as an energy source. This technology helps to produce superior effluent compared to other conventional technologies. It has many advantages over both membrane filtration and existing MBR techniques. Membrane filtration is an energy-consuming process; many studies found that AnMBRs are energy efficient, reliable and practical in wastewater management [72,74]. AnMBRs have also proven to be economically feasible. They produce pathogen-free effluent with adequate nutrients, making it suitable for reuse in agriculture [75]. Its high treatment capacity, small carbon footprint, operation even at a low reactor volume, minimal requirement for supervision, low sludge production and high stability during extreme purification make it practically suitable for wastewater purification [72,76]. A few of the many advantages of AnMBRs are summarized in the Table 2.

Table 2. Advantages of the AnMBR technique.

Cost Savings	Benefits to the Environment	Advantages of the Process	Operational Advantages
Reduced sludge production	Superior quality of effluent	Membrane fully removes solids from water flow	Reduced sludge handling is required
Reduced cost on sludge management	Less BOD	Large microbial biomass removes organics completely	Minimal operation charge and supervision
Less energy consumption	Reduced carbon footprint	Minimum supervision and care	Negligible maintenance
Reduced chemical requirement	Less harmful sludge	Can remove high organic content	
Biogas generation, may be used for energy production	Pathogen free effluent can be used in agriculture	Higher removal capacity of TDS	

(g) MOF (metal–organic framework)

This is a coordinated polymeric structure made up of a highly porous organic–inorganic hybrid framework. The framework is composed of inorganic metal ions and linkers that are organic ligands. A MOF has pores on the surface of characteristic size, shape and function, depending on its composition [77]. They may function as adsorbers, depending upon the pore size on their surfaces and the materials used (Figure 6). They may also be used as photocatalysts. Photocatalyst activity is more advantageous than adsorption in the process of WWT. A magnetic MOF (Fe_3O_4@MOF-235(Fe)–OSO_3H) was found to be effective for the removal of Cd^{II} from wastewater flows [78]. Incorporation of graphene oxide (GO) in MOF has also been found to increase the efficiency of different MOF towards Cd^{II} [78]. The major drawbacks of this system are its chemical use, thermal stability and poor processivity, which can be improved by using other functional materials [79]. This will be the subject of further research.

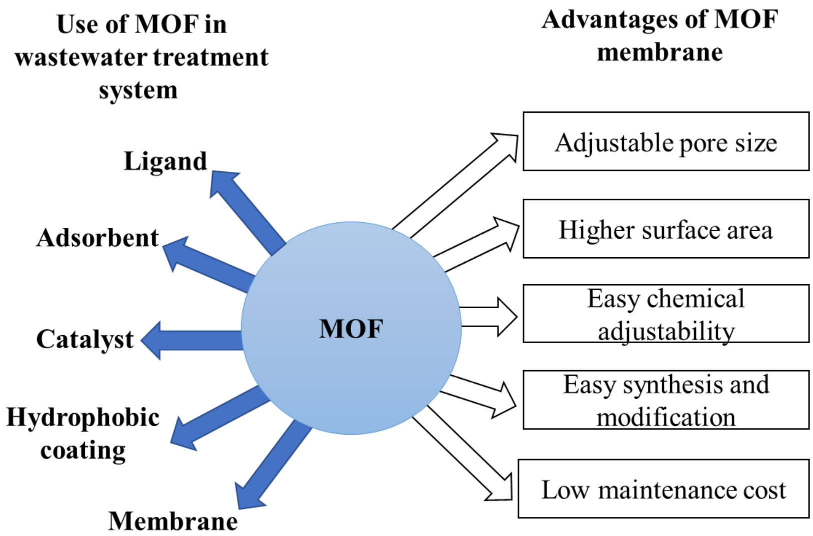

Figure 6. Use of a MOF during wastewater treatment and its advantages.

(h) MXenes

MXenes are basically several-atoms-thick, two-dimensional inorganic materials, basically consisting of nitride, carbide and other transition metals [80] with fluorine, oxygen or hydroxyl terminated surfaces; thus, they are hydrophilic in nature. MXenes are used for various purposes, but more recently they have been used in water purification systems owing their biocidal and desalinization properties. MXene made of Ti_3C_2 showed high bactericidal activity against *E. coli* (gram negative) and *B. subtilis* (gram positive), including almost 98% destruction capacity with 4 h of exposure by damaging the bacterial cell membrane [81]. MXenes based on different nanomaterials ($Ti_3C_2T_x$ [82], $NaTi_2$ $(PO_4)_3$ [83] have so far been applied to remove salt from sea water and were found to be advantageous over the conventional methods [84]. Suitable MXenes can be effectively used to treat wastewater for removal of infectious microbes and harmful or excess salt, but this requires meticulous and in-depth research (optimizations, testing, monitoring, etc.) before scale-up.

5. Electrochemical Treatments

Purification of different wastewaters can be carried out by various electrochemical treatments. It is a physiochemical technology to separate metal ions from wastewater. In this process, the cathode's surface is plated with metal ions, and they are recovered in the elemental state after the completion of the chemical reaction. Different types of electrochemical methods are used to precipitate metallic ions from water samples. These are electro-coagulation, electro-flotation, electro-oxidation and electro-deposition. The advantage of this procedure is that it has a low impact on the environment, and the handling is simpler than that of other techniques. Electrochemical treatments cannot be used widely, as they consume lots of power [36]. Electro-coagulation can substitute the use of chemicals during the chemical coagulation process, as the electrodes supply the coagulant in the water. Electro-oxidation provides much energy in the solution that can break chemically resistant organic compounds. Thus, electro-oxidation is effective against various strong organic compound disruptions and inactivation of bacteria [85].

Suspended organic and inorganic materials wastewater (WW) is also contaminated with various pathogenic bacteria, virus and protozoans. These organisms are a serious threat to the human population. Several times, they have emerged as the cause of an infectious disease. Cyanobacteria grow faster than others in aquatic systems and deplete DO in water bodies. Some of the cyanobacterial pathogens also release toxic chemicals which result in the death of aquatic organisms, and some of them are also harmful to humans [85]. All of the conventional technologies are not equally efficient against small microorganisms. Disinfection of effluents by chemical or physical agents plays important role in preventing the spread of pathogens through contaminated wastewater streams.

6. Disinfection

This is the final treatment procedure and includes the use of potential disinfectants such as chemical oxidants, chlorine compounds, ozone and ultraviolet rays to kill the remaining pathogenic bacteria or viruses after tertiary treatment. This makes the wastewater reusable.

6.1. Pathogenic Micro-Organisms and Their Removal by Disinfection

Removal of the pathogenic strains is necessary to prevent the spread of water-borne diseases. A brief account of the pathogenic and harmful microorganisms present in domestic wastewater and their possible removal is discussed.

(a) Bacterial pathogens

Single-celled organisms exist in different shapes, such as cocci—spherical; and bacilli—rod-shaped. They reproduce by binary fission. Bacteria can be divided into different groups of anaerobic, aerobic, facultative and obligate types depending on their habitats. An aerobic bacterium requires oxygen for growth, whereas anaerobic bacteria do not grow in the presence of a particular environment. A main feature of bacteria is that they are mostly free-living microorganisms. Several pathogenic strains of *Salmonella* spp., *Shigella* spp., *Escherichia* spp., *Leptospira* spp., *Klebsiella* spp. and *Pseudomonas* spp. are among the major bacterial pathogens for human beings that are present in WW flows [86]. The concentration of bacteria is very high in clinical and domestic wastes, especially in water with feces. An antibiotic can kill micro-organisms to get rid of them in infected persons. Many bacteria become resistant to antibiotics due to their continuous exposure. Enteric bacteria are mostly in the family Enterobacteriaceae. These bacteria cause several water-borne diseases and create gastrointestinal problems. An enterohaemorrhagic infection caused by pathogenic

E. coli damages the gastrointestinal tract. It may cause hemolytic uremic syndrome, meningitis and gastroenteritis-like infectious diseases [87,88].

(b) Enteric bacterial pathogens

The transmission route of these bacteria is through fecal-route exposure in aquatic bodies. The water-contaminated members of this group are *Vibrio*, *Aeromonas*, *Shigella*, *Yersinia* and pathogenic strains of *E. coli* [86,89]. The toxin produced by serotypes of *V. cholera* may cause devastating water-borne disease, such as cholera. The symptoms of cholera include dehydration watery-like feces and loss of electrolytes. *Aeromonas hydrophila*, a hydrophilic, enteric-like bacterium is the root cause of gastrointestinal infections found in the environment. They opportunistically infect humans and create gastrointestinal problems [86]. To destroy these harmful waterborne pathogenic bacteria and their strains, disinfectants are used. Disinfectants are basically chemicals that kill the pathogens that exist in untreated water. Thus, chemically treated water should be free from enteric and enteric like bacteria. Disinfectants improve the water quality and make it usable to human community with low risk. Outbreaks of diseases due to the presence of these kinds of bacteria are common if water is not treated properly. At present, the spread of waterborne infectious diseases is successfully prevented by the use of disinfectants [90]. Harmful Campylobacter present in wastewater is harmful for human beings and other organisms. The bacteria enter into the body through untreated water consumption and cause acute gastroenteritis diseases [91]. Due to its helical structure, it is found that it is genetically related to Helicobacter spp. and could be a main cause of food borne and water-borne gastroenteritis. *Helicobacter pylori* are responsible for gastric diseases and gastric cancer [92]. Reiter's syndrome is a bone disease also caused by *Campylobacter jejuni* and other genitourinary or gastrointestinal pathogens. The outcome of Reiter's syndrome is a bone joint problem which further leads to arthritis [93]. The remarkable carriers of infection may be domestic or wild birds, and some species of warm-blooded animals such as pets. Campylobacter are controlled by conventional treatment and disinfection. Aerobacter is a species that causes food- and water-borne diseases. It has been identified in all types of wastewater samples.

(c) Protozoa

Toxoplasma gondii is a most common parasite found in warm blooded animals; and infections can occur through raw or uncooked food, sand boxes or water contaminated with cat feces [94]. Infection in a mother by wastewater exposure can result in abortion, blindness or mental retardation [95]. As most of HIV patients have weakened immunity, it causes fatal CNS toxoplasmosis in HIV patients [96]. *Cyclospora cayetanesisis*, a food-borne pathogen, also spreads through wastewater contamination. Feces of infected persons contain the organisms and their oocytes. Oocytes are smaller in size, being 8–10 µm in diameter. Oocytes can be removed from contaminated water by conventional treatment methods [97]. *Acanthamoeba* spp. is an organism belongs to the family of amoeba. Acanthamoeba infects the human population through the lungs, eyes, nose and skin breakages and causes acanthamoeba keratitis and encephalitis. A few species also cause inflammation in the cornea upon infection in the eyes. People who wear contact lenses are more susceptible to it. Persons with weak immunity get infected by the pathogen easily, which produces severe diseases such as amoebic encephalitis (GAE). Acanthamoeba is pathogenic in nature; it can be a host for other waterborne bacteria [98].

There are many other protozoans, such as *Cryptosporidium parvum*, *Giardia duodenalis* and *Cryptosporidium hominis*, that are frequently found in WW bodies. *Giardia* and *Cryptosporidium* are among the intestinal parasitic causes of diarrhea in human. The unicellular flagellate protozoa of *Giardia* cause intestinal infection and giardiasis. Other pathogenic protozoa, such as *Entamoeba histolytica* and *Cyclospora*, also cause various waterborne diseases in human beings [97,99]. *Legionella, Mycobacteria and Helicobacter pylori* make groups of bacteria more resistant to antibiotics and disinfectants. Controlling both types of pathogens in water is difficult. The conventional methods remove all large amoeba-like protozoans pathogen easily.

(d) Cyanobacterial pathogens

Photosynthetic bacteria are also referred as blue green algae. Blue green algae mainly grow in water bodies and are fast growing in nature. Due to their fast growth, they cover the water bodies and deplete the dissolved oxygen level. Most of the cyanobacterial species also release chemicals and toxins and become a threat for whole aquatic ecosystem [74]. The toxins are also harmful for large-bodied animals. Cyanobacterial toxins enter into the body by the consumption of the contaminated water.

A number of cyanobacterial species (e.g., *Microcystis, Oscillatoria, Anabaena*, Nostoc) produce harmful toxins, such as liver and nerve toxins. Cylindrospermopsin (CYN) and families of microcystin and nodularin are liver toxins. CYN can also affect the organ systems such as the kidney, thymus and heart [100,101]. A family of neurotoxins, anatoxin dsaxitoxin and β-N-methylamino-L-alanine (BMAA) are also produced by the cyanobacterial species [102]. It gives a competitive growth benefit over non-toxin-producing cyanobacteria and algae. Other toxins, such as cyanotoxins, can lead to infection in wild animals, and human death [103]. Consumption of BMAA toxins causes a motor disease in humans that is similar to Alzheimer's disease and promotes cell death [104]. Treatment with algicide and disinfectant of algal blooms in waterbodies may increase toxin levels. However, with the help of conventional water treatment, microcystin concentration was reduced by 90–99% in the US [105]. Use of a single chlorine and chloramine disinfectant cannot reduce the cyanobacterium-produced toxins [106]. Various MF techniques are useful to separate the harmful pathogenic organisms and their toxins from the source water system.

6.2. Chemical Oxidants

It has been used basically for the changes in oxidation state in constituents. It can eliminate almost all the pathogenic organisms. However, it has a disadvantage of generating reactants that may be harmful in the future. Conventional and advanced methods are used in chemical treatment. In conventional methods, water is treated with chemicals such as chlorine, ozone and peracetic acid. In addition to chemicals, UV radiation is also used to disinfect the DWW. In second method, advanced oxidation processes (AOP) are used. AOP is carried out by addition of ozone with hydrogen peroxide, ozone with UV radiation, hydrogen peroxide with UV radiation or UV radiation with titanium dioxide, and several other methods [107,108].

(a) Chlorine

Chlorine is the most widely used chemical oxidant used as a disinfectant of water bodies. It inactivates the pathogen deactivating their enzymes directly or indirectly by changing the pH of water. In contact to water, chlorine gas produces hydrochloric acid (HCL) or hypochlorous acid (HOCl), which is toxic to the waterborne pathogens. Chlorine oxide is another germicidal with high oxidation power. It kills the microorganisms by inactivating their enzymes and interfering with the protein synthesis capability [107].

(b) Ozone

It is a more effective oxidant than the others. It reduces the color of bad water, and taste and odor-causing compounds; natural organic matter is converted into other forms by biodegradation. Ozone makes the water effectively reusable. It is a stronger oxidizer than chlorine compounds. It destroys the cell walls of bacteria and thus is capable of directly killing them [107].

(c) Peracetic acid (PAA)

PAA is a well-known water disinfectant that is used as an alternative to chlorination. PAA, when in contact with water, decomposes into acetic acid and oxygen. The release of reactive oxygen in water produces hydroxyl molecules which degrade the cell wall, cell membrane, enzymes and DNA or RNA of microorganisms.

(d) Hydrogen peroxide (H_2O_2)

Hydrogen peroxide (H_2O_2) is used as potent disinfectant due to its higher oxidation power than chlorine. After dissolving, it produces hydroxyl molecules and different superoxide radicals which kill the microbes in water by affecting cell structure and functions. It can inactivate pathogenic bacteria, bacterial spores, virus and fungi suspended in WW streams [109].

(e) Advanced oxidation processes (AOP)

Ozone with hydrogen peroxide: both ozone and hydrogen peroxide are highly efficient oxidizing compounds. In water, they produce hydroxyl radicals, which are toxic to the microorganisms present in WW streams. Using both of them increases the efficiency of the oxidative disinfestation process. This was found to be successful against the cysts of *Giardia muris* [108].

(i) Ozone with UV radiation: The combination of ozone with UV radiation destroys the pathogens by both oxidation and photochemical reaction. UV is harmful to the biotic organisms, as it induces mutation and damage to the DNA. UV also induces the efficiency of the reactive oxygen molecule formation capacity of ozone and thus induces oxidative damage in the pathogen. It was found to be effective against the *E. coli*, *Giardia*, *Cryptosporidium* and several other pathogens [110].

(ii) Hydrogen peroxide with UV radiation: It also includes both oxidation and photochemical inactivation of pathogen and is also effective against a broad range of bacterial and fungal pathogens, including more persistent cyst- and endospore-causing ones.

UV radiation with titanium dioxide: This is another AOP by which the oxidative efficiency of TiO_2 is increased by the photochemical treatment. Although this is effective against all pathogens, toxic trihalomethanes are produced during this treatment. The advantages and disadvantages of different conventional WW treatments are explained in Table 3.

Table 3. Advantages and disadvantages of different water purification techniques.

Waste Water Purification Techniques	Advantages	Disadvantages
Sedimentation	1. Simple, cost-effective and efficient removal of large suspended particles.	1. Not sufficient for removal of colloids and other smaller insoluble molecules.
Coagulation and flocculation	1. Simple and integrated physicochemical process. 2. Inexpensive and easily available chemicals. 3. Significant reduction in the COD and BOD. 4. Easy sludge disposal. 5. Efficient insoluble matter removal capacity.	1. Further processing of effluent is required. 2. Dissolved impurities and ions cannot remove. 3. Limited removal capacity of pathogens.
Precipitation	1. Simple Physicochemical process. 2. Economically advantageous. 3. Effective removal of phosphorous and nitrogen substances. 4. Efficient removal of metal and fluorides. 5. Reduction in COD and BOD.	1. No metal selectivity. 2. At lower concentration metal removal is inefficient. 3. High sludge production creates problem in sludge management.
Filtration	1. Simple and cost-effective process. 2. Wide variety of targets and also separate microbial toxin and pathogens.	1. Small particles can pass through membrane so, not efficient for removing all kind of pathogen. 2. Weak or no selectivity.

Table 3. *Cont.*

Waste Water Purification Techniques	Advantages	Disadvantages
Adsorption	1. Low cost highly effective. 2. Effective against wide variety of target molecules. 3. Applicable at wide pH range. 4. Low footprint.	1. Low selectivity. 2. Rapid saturation and clogging problem. 3. Regeneration of activated carbon is costly.
Trickling filter	1. Simple filtration process. 2. No chemicals are used hence safer than others. 3. Reduction in the level of BOD. 4. Low energy consumption and durable. 5. Suspended organics are removed efficiently.	1. Alone is not sufficient. 2. Biofilm thickness should be under control so regular attention is required.
Biosorption	1. Simple and cost-effective process. 2. No chemical used. 3. Efficient removal of HMs. 4. Sludge production is low.	1. Depends upon the pH of solution. 2. Depends upon the present biomass.
Activated sludge processing (ASP)	1. Lower installation cost. 2. Good quality effluent with reduced organics and pathogen.	1. Hydraulic retention time is longer. 2. Higher operation cost. 3. Large amount of sludge.
Membrane bioreactor (MBR)	1. Lower footprint. 2. Can filter all pathogen, solids, and biological waste. 3. High efficiency than ASP. 4. No chemical usage. 5. Low footprint.	1. High operational cost. 2. Membrane fouling is common problem.
Ion-Exchange	1. Simple effective and efficient. 2. Selective recovery of metals. 3. Small volume of sludge production and thus easy disposal.	1. Maintenance is costly. 2. Depends upon the presence of optimum metal concentration. 3. Sensitive to pH.
Membrane filtration Microfiltration (MF)	1. Algae, protozoa, bacteria, and sediment particles are separated easily. 2. Low operating pressure and low energy consumption.	1. Cannot remove virus. 2. Membrane sensitive to oxidative chemicals. 3. High pressure cause membrane damage.
Ultrafiltration (UF)	1. Lower pressure and lower energy consumption. 2. Removal of bacteria and a smaller extent to colloids, virus and phage.	1. Unable to remove virus. 2. Damaged by larger molecule or high pressure. 3. Oxidative, chemical sensitive.
Nanofiltration (NF)	1. Exclude salts from water. 2. Exclude nitrate, sulphate and pathogens from water. 3. Can remove colour and HMs.	1. Not durable. 2. High pressure induces power consumption. 3. Membranes are costlier than others. 4. Limited retention for univalent ions.
Reverse osmosis (RO)	1. Removal of all ions. 2. Removal of viruses. 3. Chemical free process. 4. Removal of colour and toxins.	1. High power consumes higher energy. 2. Costlier membrane. 3. Sensitive to oxidants.

Table 3. *Cont.*

Waste Water Purification Techniques	Advantages	Disadvantages
Electrochemical treatments	1. Recovery and recycling of valuable metals like gold and silver. 2. Increase biodegradability. 3. Remove suspended solids, tannins and dyes.	1. Consume power and hence costly. 2. Electrodes are not durable. Deposition of sludge interfere with electrode activity. 3. Sludge management increase the operating cost.
Disinfection Chlorination	1. Inactivation bacteria and viruses. 2. Reduce the chance of recontamination. 3. Easy to use and cost-effective.	1. Change in odour and taste. 2. Lower protection against protozoans. 3. Long term effects of biproducts.
Ozonisation	1. Generation of superoxide and hydroxyl. molecule disrupt the microbial physiology and inactivates them. 2. Alternative to chlorination. and environmentally friendly.	1. Costly process. 2. Produce toxic biproducts. 3. High reactivity. 4. Low water solubility.
UV	1. Cost effective. 2. Kill all microorganisms. 3. No chemical usage thus environment friendly process.	1. Cannot remove soluble impurities.
AOP	1. Rapid reaction rate and small footprint. 2. Kill all microorganisms and viruses.	1. Costlier than others. 2. Superoxide molecules are not removed after treatment.

7. Conclusions and Future Prospects

Water bodies get contaminated by industrial, agricultural and household waste through WW flow. Waste materials contain various organic, inorganic, synthetic soluble and insoluble components, which may change the physical and chemical properties of water. They also change the DO, COD and BOD of water, which harms the aquatic organisms. Wastewater also contains various unwanted pathogenic bacteria, fungi, protozoa and viruses. They are responsible for several diseases, such as cholera, diarrhea, campylobacteriosis, giardiasis, leptospirosis and various others in humans. Cyanobacterial toxins, ascariasis, hookworm and ringworm infections also occur through contaminated water. Thus, WW purification becomes necessary to prevent the water pollution and prevention of waterborne diseases. Conventional WW treatment can efficiently decontaminate water from many contaminants, but with different efficiencies. The advantages and disadvantages of different conventional WWTs are summarized in Table 2. Surface water is getting polluted day by day, which reduces the available freshwater resources. The release of DWW into freshwater bodies is a major reason for cultural eutrophication. Moreover, the emerging contaminants have aggravated the problems of WWT regimes. Organic matter suspended in WW can be a nutrient source for agriculture. Extraction and reuse of both organics and effluent water by conventional methods would help the sustainable use of water resources. Application of conventional WWT processes to treat DWW before releasing it into the surface water bodies may become useful to prevent water pollution. To safeguard the health of an increasing population, the government of every country should take proper steps to formulate the application of an effectual WWT technique. As aforementioned, wastewater may be a nutrient-rich source for agriculture, but the chemicals and ions are toxic to the plants. After reducing the toxic chemicals through various treatments, wastewater can be used in agriculture. National policy to reuse wastewater in agriculture is important in this era of water scarcity. Collaborative efforts of academia and institutions are necessary for the successful implementation of government policies in the treatment and reuse of wastewaters.

Nowadays, various biotechnological approaches have emerged for effective WWT processes. In this approach, genetically modified microorganisms are used as degraders of organic materials and as removers of contaminants from wastewaters. Although each conventional method has various advantages, alone they are not efficient at removing all the impurities from the wastewaters. They may be used in combination to efficiently remove all organic and inorganic impurities. Thus, a robust technique should be developed with regard to water purification. The innovative approaches should be tested, monitored and applied, especially in low and middle-income countries where most municipal wastewater still goes untreated into the environment [27,111].

WWT techniques must be selected, in the future, based on their energy efficiency, waste removal efficiency and greenhouse gas releasing efficiency. An effective and efficient system consuming less power must be promoted. Increasing urban population will reduce the free space for installing large purification systems, and thus, more compact systems with lower carbon footprints will be in demand. In our opinion, researchers should be more concerned with developing highly efficient, less power consuming, less fouling, cost-efficient and compact systems to purify sewage water from various sources. Under the concept of the circular economy, phytoremediation through hyper accumulator algal species must be promoted, as they have the potential to bring radical changes to WWT regimes. It shall prove to be useful, cost-effective, ecofriendly and reliable WWT strategy in remediation of emerging wastewater contaminants also. Moreover, the valorized biomass can be used to generate value-added products (recycle) such as biofuel and fertilizers.

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Abbreviations

DWW—Domestic wastewater; DWWT—Domestic wastewater treatment; CDC—Centre for Disease Control and Prevention; IPR—Indirect potable reuse; MWW—Municipal wastewaters; WW—Wastewater; TDS—Total Dissolved Solids; DOC—Dissolved organic carbon; SMP—Soluble microbial products; LAS—Linear alkyl benzene sulfonates; DOD—Dissolved oxygen demand; DO—Dissolved oxygen; BOD—Biochemical oxygen demand; COD—Chemical oxygen demand; TOC—Total organic carbon; WWT—Waste water treatment; HMs—Heavy metals; UV—Ultraviolet; ASP—Activated sludge processing; AS—Activated sludge; MBR—Membrane bioreactor; MF—Microfiltration; UF—Ultrafiltration; NF—Nanofiltration; RO—Reverse osmosis; EDR—Electrodialysis reversal desalination; PVDF—Polyvinylidene fluoride; ARB—Antibiotic-resistant bacteria; ARG—Antibiotic resistance genes; BSMBRs—Biomass separation membrane bioreactor; AnMBRs—Anaerobic Membrane Bioreactors; IEMBRs—Ion exchange membrane bioreactors; EMBR—Extractive membrane bioreactor; MABRs—Membrane aeration bioreactors; CNS—Central nervous system; HIV—Human immunodeficiency virus; CYN—Cylindrospermopsin; BMAA—β-N-methylamino-L-alanine; AOP—Advanced oxidation processes; HOCl—Hypochlorous acid; PAA—Peracetic acid; STPs- Sewage treatment plants.

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