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Review

The Role of Conventional Methods and Artificial Intelligence in the Wastewater Treatment: A Comprehensive Review

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Abstract: Water pollution is a severe health concern. Several studies have recently demonstrated the efficacy of various approaches for treating wastewater from anthropogenic activities. Wastewater treatment is an artificial procedure that removes contaminants and impurities from wastewater or sewage before discharging the effluent back into the environment. It can also be recycled by being further treated or polished to provide safe quality water for use, such as potable water. Municipal and industrial wastewater treatment systems are designed to create effluent discharged to the surrounding environments and must comply with various authorities' environmental discharge quality rules. An effective, low-cost, environmentally friendly, and long-term wastewater treatment system is critical to protecting our unique and finite water supplies. Moreover, this paper discusses water pollution classification and the three traditional treatment methods of precipitation/encapsulation, adsorption, and membrane technologies, such as electrodialysis, nanofiltration, reverse osmosis, and other artificial intelligence technology. The treatment performances in terms of application and variables have been fully addressed. The ultimate purpose of wastewater treatment is to protect the environment that is compatible with public health and socioeconomic considerations. Realization of the nature of wastewater is the guiding concept for designing a practical and advanced treatment technology to assure the treated wastewater's productivity, safety, and quality.

Keywords: water pollution; precipitation; adsorption; membrane; artificial intelligence

Citation: Altowayti, W.A.H.; Shahir, S.; Othman, N.; Eisa, T.A.E.; Yafooz, W.M.S.; Al-Dhaqm, A.; Soon, C.Y.; Yahya, I.B.; Che Rahim, N.A.N.b.; Abaker, M.; et al. The Role of Conventional Methods and Artificial Intelligence in the Wastewater Treatment: A Comprehensive Review. *Processes* **2022**, *10*, 1832. https://doi.org/10.3390/pr10091832

Academic Editor: Andrea Petrella

Received: 9 August 2022
Accepted: 7 September 2022
Published: 12 September 2022

1. Introduction

There are generally three types of wastewater or sewage: domestic, industrial, and storm sewage [1]. Domestic wastewater, also called sanitary sewage, is wastewater either from blackwater (wastewater from toilets that contain feces, urine, or toilet paper) or greywater (water from sinks, baths, washing machines, and others) [2].

Pollution and exorbitant use seriously compromise the availability of fresh and clean water around the earth and may cause a critical impact in the future. It is mandatory to protect and produce healthy water of sufficient quality at an economical cost while conserving the ecosystems. Every country will release liquid and air emissions and solid wastes. Wastewater is essentially the water supply that comes from the people in the city after it has been used in various applications [3].

From a practical standpoint, wastewater includes dissolved and suspended organic solids. These are waste that contains organic matter capable of decomposition by microorganisms and of such a character and proportion that causes odors and the capability to attract or provide food for ecosystems like birds and other animals. Another principal physical characteristic of wastewater can be defined by its color and temperature [4]. The color function explains the basic condition of wastewater. Wastewater with the color light brown is less than 6 h old, while light to medium grey color is wastewater that has been processed in the collection system. Finally, the wastewater is typically septic, undergoing immeasurable germs decomposition under anaerobic conditions if the color is dark grey or black. Next, the wastewater temperature is frequently higher than that of the water supply because warm municipal water has been added. The temperature of wastewater will vary from different weather and also with geographical locations.

Wastewater treatment is a process in which the solids in wastewater are partially removed and changed. Designing wastewater treatment facilities need to base on the characteristics of the wastewater. Table 1 lists some key characteristics of concern [5].

Table 1. Design factors consider wastewater's physical, chemical, and biological properties.

Physical	Chemical	Biological
Solids Temperature Colour Odor	Organic substances include proteins, sugars, lipids, surfactants, phenols, and insecticides. Inorganics: heavy metals, hazardous substances, alkalinity, nitrogen, phosphorus, and pH. Gases: Oxygen, hydrogen sulfide, methane	Plants Animals Viruses

The following main categories can be used to group water treatment technologies: Energy-intensive methods, chemical methods, and physical methods [6].

Physical methods are the main water treatment technology. Recirculation technologies can be divided into two parts—conventional and non-conventional. To recognize the role of recirculation, it is important to conduct a variance study about the cleaning and purification of industry and urban waters with the different unit processes [7].

Chemical treatment methods depend on the chemical reaction of the contaminants that the community removes from water and the inquiry of chemicals that encourage pollution from water. This method can be applied as a stand-alone or fundamentally with physical techniques [8].

Next, energy-intensive technologies, including the generated electric current, are applied to drinking water applications [9].

In this review, the first part determines the classification of water pollutants. It aims to provide an overview of the water pollutant and what chemicals and materials can produce wastewater. The following three sections discuss the common conventional method for wastewater treatment, including precipitation, adsorption, and membrane technologies. Moreover, the last part of this review explains the role of artificial intelligence models in wastewater treatment. These three conventional technologies groups can integrate into water treatment or merge by referring to the aim of the water treatment. The option to achieve the objective of water treatment not only depends on the technology's functionality but on choosing a suitable method of water treatment, which also depends upon such factors as (1) the cost of purifying the water, (2) the effectiveness after using the technologies, (3) the quantity of water and environment need to manage, (4) the materials and tools need to use to separate the waste. The above explains the difficulty of choosing the ideal technologies to treat water. To evolve the water treatment technologies, we need to consider the cost-effective design; we need to identify many aspects and the knowledge of operating the technologies. To the best of our knowledge, this is the first review highlighting conventional methods and artificial intelligence in wastewater treatment. A bibliometric analysis of the most recent publications between 2012 and 2022 is carried out to evaluate the research bias on artificial intelligence in wastewater treatment. The main purpose of bibliometric indicators is to visually represent the significant elements pertaining to scientific subjects. The most significant publications and countries were identified in the current review using bibliometric markers such as co-authorship analysis. The largest database for scientific research publications is Scopus, which includes information on all current research fields. It is utilized in this research. Additionally, OSViewer (version 1.6.18) is utilized in this paper. VOSviewer has been developed by Nees Jan van Eck and Ludo Waltman at Leiden University's Centre for Science and Technology Studies (CWTS) in the Netherlands.

2. Classification of Water Pollutants

Wastewater consists primarily of water with the remaining solid, which can be in either dissolved solid or suspended solid form that may be classified as organic, inorganic, and biological [10]. In addition, there are also thermal and radioactive pollutants discharged from power plants, nuclear plants, and industries where water is used as a coolant, mining, etc. [11]. The types of contaminants found in the wastewater depend on the activities that release municipal, industrial, or agricultural wastewater. The four main types of water contaminants are suspended solids, microorganisms, and organic and inorganic pollutants. These contaminants in the water continue to exist in solvated, colloidal, or suspended forms.

2.1. Organic Pollutants

The organic matter in municipal wastewater originates primarily from residential and commercial food processing and urine and feces [12]. This pollutant, with a considerable concentration of biodegradable organic compounds, undergoes degradation and decomposition by bacterial activity [13]. Wastewater is processed by biological treatment to remove organic matter. However, approximately 30% of the organic matter is still not biodegradable and must be disposed of as waste sludge [14].

Some contaminants include synthetic pesticides, detergents, food additives, medicines, insecticides, paints, synthetic textiles, plastics, solvents, and volatile organic compounds [15]. There are also synthetic organic compounds found in wastewater due to various artificial activities such as agricultural and industrial activities. For instance, the wastewater discharged by the food industry may contain complex organic pollutants with a high concentration of BOD, and the coke plant wastewater may contain various polynuclear hydrocarbons. The wastewater of the chemical industry may contain various carcinogenic compounds like PCB (polychlorinated biphenyls, widely used as coolant fluids). The wastewater of the farmland may contain a high concentration of pesticides or herbicides [16]. Most toxic synthetic organic pollutants are resistant to decomposition by ordinary biological mechanisms. Carcinogenic PCB has been widely used in industries since the 1930s. It is fat-soluble and moves easily through the environment and within the tissues and cells with high stability to chemical reagents [17].

In addition, an oil complex mixture of hydrocarbons and degradable under bacteria action is also considered one of the organic pollutants [18]. Oil may enter the water body through oil spills, leakage of oil pipes, and wastewater produced from refineries and production factories. With a density lesser than water, it may spread over the surface of the water body, resulting in a decrease of dissolved oxygen and reduction of light transmission through the water surface and affecting the life of aquatic flora and fauna.

The two primary techniques used to determine the amount of organic matter are chemical oxygen demand (COD) and biochemical oxygen demand (BOD). One of the most crucial factors in the design and operation of sewage treatment facilities is the BOD, which measures the biodegradability of organic matter. Industrial sewage may have BOD levels many times than domestic sewage. Dissolved oxygen (DO) is an important water quality factor for lakes and rivers. The higher the concentration of DO, the better the water quality. When sewage enters a water body, decomposition of the organic matter begins as organic matter is served as food in the microorganism metabolism process. The microorganism's population will grow and lead to the increase in consumption of DO in the water body, which next may then affect the aquatic living organisms. A decrease of dissolved oxygen below 4.0 mg/L is considered pollution [19].

2.2. Inorganic Pollutants:

Water quality is established and controlled by several inorganic components that are present in both natural and effluent. Natural water dissolves rocks and minerals with which they come in contact. Much of the inorganic matter in natural waters is also in wastewater. However, much of the inorganic matter is added via human activity, such as nitrite ions [20].

The inorganic pollutants include mineral acids, inorganic salts, trace elements, nitrates, phosphates, sulfates, fluorides, chlorides, oxalates, cyanides, etc. [21]. For example, municipal wastewater may contain excessive nitrates and phosphorus from phosphate builders in detergents [22,23]. The high phosphorus content may lead to the eutrophication of water bodies. The rapid growth of algae in the lake is harmful and has a negative effect on the entire food chain, as some of these algae may produce toxins. Another example of an inorganic pollutant is sulfate, where its ion in wastewater may reduce biologically to sulfide. It then combines with hydrogen to form hydrogen sulfide (H_2S), which is toxic to animals and plants. Toxic inorganic compounds such as copper, lead, silver, arsenic, boron, and chromium are classified as priority pollutants and are toxic to microorganisms [24,25]. These pollutants can kill off the microorganism needed for biological treatment in the wastewater treatment process.

The most prevalent inorganic water contaminants are also heavy metals. They are very poisonous, naturally carcinogenic, non-biodegradable, and may linger in the environment and food supply. The removal of heavy metal ions from diverse wastewater sources has been addressed using various approaches [26]. These procedures might be divided into categories such as adsorption, membrane-, chemical-, electric-, and photocatalytic-based therapy [27]. Among the heavy metals with a high atomic mass are plutonium, mercury, lead, cadmium, zinc, arsenic, and chromium. There is no safe amount of exposure to lead since it is a hazardous metal that originates through the exhaust of vehicles that use leaded gasoline [28]. Table 2 shows some typical heavy metals in wastewater that affect human health.

Table 2. Common heavy metals found in wastewater, their origins, and the health problems they cause [27].

Heavy Metal	Main Sources	Main Organ and System Affected
Lead (Pb)	Lead-based batteries, leaded gasoline, alloys, cable sheathing pigments, rust inhibitors, ammunition, glazes, and plastic stabilizers.	Bones, liver, kidneys, brain, lungs, spleen. Immunological, hematological, cardiovascular, reproductive system.
Arsenic (As)	Electronics and glass production.	Skin, lungs, brain, kidneys. Metabolic, cardiovascular, immunological, and endocrine systems.
Copper (Cu)	Corroded plumbing systems, electronic and cables industry.	Liver, brain, kidneys, cornea. Gastrointestinal, lungs, immunological, hematological system.
Zinc (Zn)	Brass coating, rubber products, some cosmetics, and aerosol deodorants.	Stomach cramps, skin irritations, vomiting, nausea, anemia, and convulsions.
Chromium (Cr)	Steel and pulp mills and tanneries.	Skin, lungs, kidneys, liver, brain, pancreas. Tastes, gastrointestinal, reproductive system
Cadmium (Cd)	Batteries, paints, steel industry, plastic industries, metal refineries, and corroded galvanized pipes.	Bones, liver, kidneys, lungs, testes, brain. Immunological, cardiovascular system.

Table 2. *Cont.*

Heavy Metal	Main Sources	Main Organ and System Affected
Mercury (Hg)	Electrolytic production of chlorine and caustic soda, runoff from landfills and agriculture, electrical appliances, Industrial and control instruments, laboratory apparatus, and refineries.	Brain, lungs, kidneys, liver. Immunological, cardiovascular, endocrine, and reproductive systems.
Nickel (Ni)	Manufacturing of nickel alloys and stainless steel.	Kidney, pulmonary fibrosis, gastrointestinal problems, lung, and skin.

2.3. Microbes/Pathogens

Cholera, typhoid, polio, and hepatitis are examples of water-borne illnesses that can be spread by pathogenic microorganisms that enter a body of water by sewage discharge or through businesses like slaughterhouses [29,30]. Different kinds of bacteria that thrive in sewage might cause many ailments. Salmonella-causing bacteria, hepatitis A viruses, protozoa, fungus, algae, plankton, amoebas, and other worms like hookworm and whipworm are among the potentially dangerous germs. Escherichia coli, an intestinal bacterium secreted by all warm-blooded animals, is also measured to determine the presence of fecal contamination [31].

2.4. Suspended Solid and Sediments

Suspended solid normally is the first item to be extracted from wastewater at the beginning of the treatment plant through the screening process [32]. Items such as wet wipes, diapers, sanitary napkins, expired medication, medical packaging, and other items are flushed into the toilet even at the risk of causing blockages. Trash and garbage in the street may also be carried to the combined sewer system by stormwater runoff [33]. Industrial and storm sewage may contain more suspended solid waste than domestic sewage. In addition, the treatment plant's effectiveness in removing suspended solids also determines the efficiency of the treatment process [34].

3. Source of Pollution

3.1. Urban Pollution

Urban can be defined as the association of massively populated cities and the surrounding areas. From the definition, the crucial key of a city is that it has a lot of people, buildings, structures, and infrastructures. The smaller centered areas in the city, such as the waterways, will be affected and cause a negative impact on the environment since all people in the city share the same residential area, air, and water. Water resources in urban areas need to receive a lot of pollutants from various sources. For example, effluents from industry, vehicle sources such as oil, wastewater from housing, garbage, and rainwater are polluted due to urban landscapes [35].

The problems with the urban water can be described as 'too little, too much, too dirty.' This is because the populated areas have people intervene at high levels in the natural hydrological cycles to keep up with the water supply and storm water management. The systems for urban water are interconnecting with various systems; thus, it gets an impact indirectly and causes water issues that will also affect other problems [36].

As mentioned, there are a few sources of urban pollution, one of which is anthropogenic activities. Examples of anthropogenic activities are vehicle transportation and washing building surfaces. Based on a previous study, vehicle operation is the main cause of environmental pollution [37]. The operation includes the exhaust, fluid leakages, and washing vehicle. Exhaust gas from vehicles releases pollutants such as hydrocarbons from internal combustion engines. The leakages of the automotive fluids and the oil for the engine were reported to be likely the cause of BTEX pollutants. Other than that, washing vehicles also contribute to various chemical discharges and particles that attach to the car [38].

3.2. Agricultural Pollution

Agriculture can be expressed as the action of farming, working on the soil to produce a variety of plants, breeding livestock, and diverting the levels of preparation and marketing of the product produced. Agricultural activities have been done for thousands of years using the natural process, which does not affect soil fertility. Despite that, the current implementation of agriculture activities has been causing environmental pollution, unlike the previous agriculture practices [20,39]. This has caused the deterioration of the environment, land, and ecosystem.

The water pollution issues in agriculture modern practices are happening globally. It contemplates the possibilities of the growth of the human population and food demand increases. The result is estimated that the livestock demand will increase, mass production will occur, and the use of chemicals will intensify [40].

There are a few elements that cause water pollution from agricultural activities. The first is the soil fertilizers, be they artificial or organic; both fertilizers cause water contamination and affect aquatic ecosystems [20]. The content of nutrient in the fertilizers that helps fertilize the plants, lawns, and golf fields cause the immediate growth of algae. These algae are also known as an algal bloom, and when these algae die, they feed on the bacteria. The bacteria then will conquer the freshwater and causes the degradation of oxygen which reduce the survival rate of fish and plants in the water [41]. Furthermore, some algae can also produce toxins that can be dangerous to humans.

Apart from fertilizers, pesticides are also widely used in modern agricultural practices. The chemicals in pesticides are very toxic to insects but less toxic to mammals [42]. Based on a previous study, the substantial use of pesticides has contaminated the soil and drinking water in Central Asia. The dichlorodiphenyltrichloroethane (DDT) and lindane of organohalogen pesticides (OCPs) have been discovered in the water samples of the river. Four water samples were taken in the area where pesticides were applied. The results show that the OCPs found in the samples are hexachlorocyclohexane (HCH), DDT, and dichlorodiphenyldichloroethylene (DDE). These OCPs have been washed out from the soil and flow into the water [43].

3.3. Industrial Pollution

A large-scale business that produces goods is often correlated with the meaning of the industrial. About 19 percent of water was pulled out to be used for industrial purposes globally. For the past years until now, the industry has extensively influenced water pollution because it produces very dangerous contaminants to human beings and the environment [44]. The ecological environment in China has been facing serious impairment, particularly water pollution due to industrial activities. In addition, the physical and mental health, quality of life, and productivity of the citizens in China are also affected [45].

Some pollutants come from industrial activities, and one of them is oil. The petroleum industry is one of the major contributors towards the surface water and groundwater pollution. There are refineries that operate deep-injection wells to get rid of the wastewater produced in the plants, and some of the unusable water ends up in the groundwater [46]. The wastewater produced at the refineries is possibly greatly contaminated by looking at the total sources in contact with the procedure of the refinery. Polluted wastewater might be the product of desalting, cooling tower water, distillation water, or cracking [47].

Besides the petroleum industry, the radioactive industry also has a huge imprint on the water contamination issue. The atom is usually illustrated as the center of the nucleus with several electrons that rotate like the earth's orbit around the sun. It comprises comparatively higher protons that convey the positive electrostatic and neutrons that have no charge. If the nucleus is unstable, it is not balanced, and the atoms can be radioactive. In order to get the internal balanced, the nucleus will give out alpha or beta particles, or also can be gamma radiation, or both. [48]. Radioactivity can affect drinking water by the occurrence when groundwater moves through the soil that contains radionuclides. This is because some areas are vulnerable to pollution when the soils and rocks are rich in phosphate. The contaminants from radionuclides in drinking water can result in bone radium concentrates, and cancers and are toxic to kidneys [49].

4. Wastewater Treatment Technology

Wastewater treatment can be divided into several units of operations or processes that are selected and combined to serve its designed purposes and cater to the area under its consideration. In general, it may be separated into primary, secondary, and tertiary treatments [50].

While secondary treatment focuses on the biological treatment of wastewater, primary treatment entails first purifying procedures of a physical and chemical character. Effluent that is low in solids and organics after the primary and secondary process is fit to discharge back into the receiving water after it has been treated. These include chlorination, UV treatment, or a range of filtration options that aim to disinfect, remove the nutrients, or alter the pH after considering the receiving environment for the effluent. In tertiary treatment processes, most pollutants are removed and wastewater is converted into safe quality water suitable for human consumption, industrial, medicinal, etc. supplies [51].

In a full water treatment plant, the units from all three of these processes are chosen and integrated to create high-quality, safe water while also considering total cost, including building operation and maintenance expenses [52,53]. The overall scheme of wastewater technologies and sludge treatment is summarized in Table 3 below.

Table 3. Overall scheme of wastewater treatment technologies.

Primary	Secondary	Tertiary	Sludge Treatment and Disposal
-Screening -Centrifugal separation -Coagulation & flocculation -Floatation -Sedimentation, gravity separation	-Aerobic -Anaerobic -Encapsulation	-Oxidation/Advanced oxidation -Adsorption -Micro and ultra-filtration -Membrane bioreactor (MBR) -Reverse osmosis -Electrolysis -Electrodialysis -Precipitation -Distillation -Ion exchange -Crystallization -Evaporation -Solvent extraction	-Thickening -Digestion -Dewatering -Disposal

There are several techniques in use, and Table 4 lists several regularly employed techniques for heavy metal removal [54]. Table 4 compares several methods for removing heavy metals from wastewater.

Table 4. Comparison of technologies for heavy metal removal from wastewater.

Method	Advantage	Disadvantage	Reference
Chemical precipitation	Simple/Inexpensive The majority of metals can be eliminated.	Significant sludge production led to disposal issues	[20]
Chemical coagulation	Dewatering and Sludge settling	High price, large chemical use	[55]
Ion—exchange	high rate of material regeneration a metal-specific	High price fewer metal ions are eliminated	[56]

Table 4. *Cont.*

Method	Advantage	Disadvantage	Reference
Electrochemical Method	a metal-specific No chemical consumption Pure metals are attainable.	capital coat high high ongoing expenses the pH of the starting solution and current density	[57]
Adsorption Using activated carbon	Most metals are easily removed. high effectiveness (99%)	Activated carbon price lacking regeneration Performance is influenced by the adsorbent	[23]
Using natural zeolite	Metals may generally be removed. reasonably affordable materials	low effectiveness	[58]
Membrane process and ultrafiltration	created a less solid waste less use of chemicals high effectiveness (>95% for a single metal)	high start-up and operating costs minimal flow rates Removal (9%) falls off when additional metals are present.	[13]

4.1. Precipitation/Encapsulation

Metals must be removed from wastewater since some are hazardous to humans and animals and do not decompose in the environment. By decreasing their solubilities by adding chemicals or organic solvents (a pricey option), etc., dissolved pollutants (target more on metal ions/heavy metal, phosphate, and organics) are transformed into solid particles/precipitates in this procedure [27]. The ionic metals are changed into insoluble particles by a chemical reaction between the soluble metal complexes and the precipitating reagent. The generated particles are then filtered or settled out. The chemicals such as sodium bicarbonates, ferric chloride, ferrous sulfate, or calcium hydroxide (lime) are used. The type of ionic metals present, pH, and temperature are the main factors for the success of the process [59]. The main issue with this procedure is the significant amount of sludge generated, and the presence of oil and grease may interfere with precipitation.

The principal process in a precipitation reaction is forming a new solid phase from a solution before water is used for the human body and industry. An illustration of one kind of wastewater treatment procedure is shown in Figure 1, beginning with the environment and ending with houses.

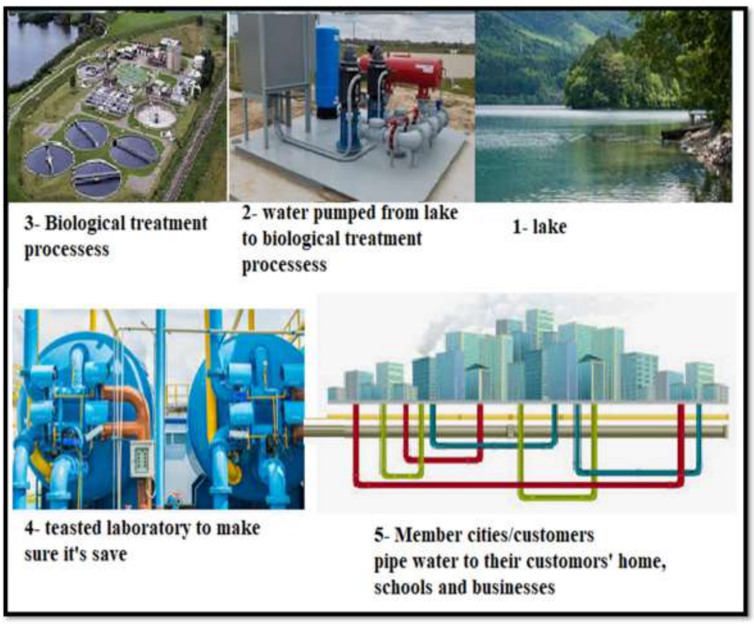

Figure 1. Block diagram of wastewater treatment facility [60].

The wastewater treatment method's precipitation step aims to purge the water of phosphates and soluble metal ions. Before performing the reactions, the first step is determining whether compounds are soluble. An illustration of a precipitation reaction in a test tube is shown in Figure 2 below. The reaction produces a solid that may be eliminated by filtering. In the precipitation reactions during wastewater treatment, the same procedure applies.

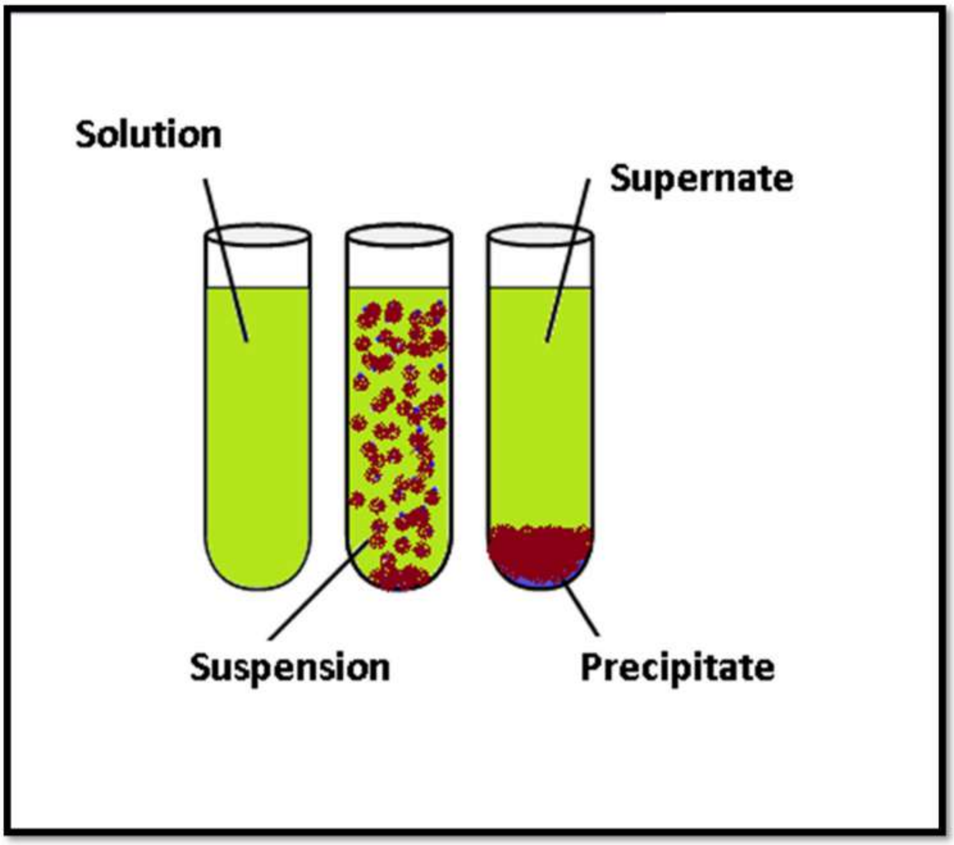

Figure 2. Precipitation reactions in wastewater treatment.

The three heavy metal removal techniques stated above are ion exchange, adsorption, and chemical precipitation [61]. However, chemical precipitation is the most popular technique for removing dissolved metals from solutions, such as process wastewaters containing hazardous metals. The ionic metal was changed into an insoluble particle by the chemical interaction between the soluble metal compounds and the precipitating agent. The particles produced by this reaction are eliminated from the solution by settling or filtering. The type and quantity of ionic metals present in the solution, the precipitant utilized, the reaction conditions, and the existence of other components' reactions are some parameters that must be considered for the chemical precipitation process to work well. The most economical method to remove metals from wastewater is calcium hydroxide (lime), which is often used in the chemical precipitation process. Ion exchange is the second technique most frequently utilized in the water treatment sector. This technique is also cost-effective; the ion exchange process effectively removes heavy metals from aqueous solutions and often uses inexpensive components and simple procedures. The wastewater treatment may be easily distinguished and includes the following processes: screening, sedimentation, precipitation, filtration, absorption, and disinfection. The steps of wastewater treatment are depicted in Figure 3.

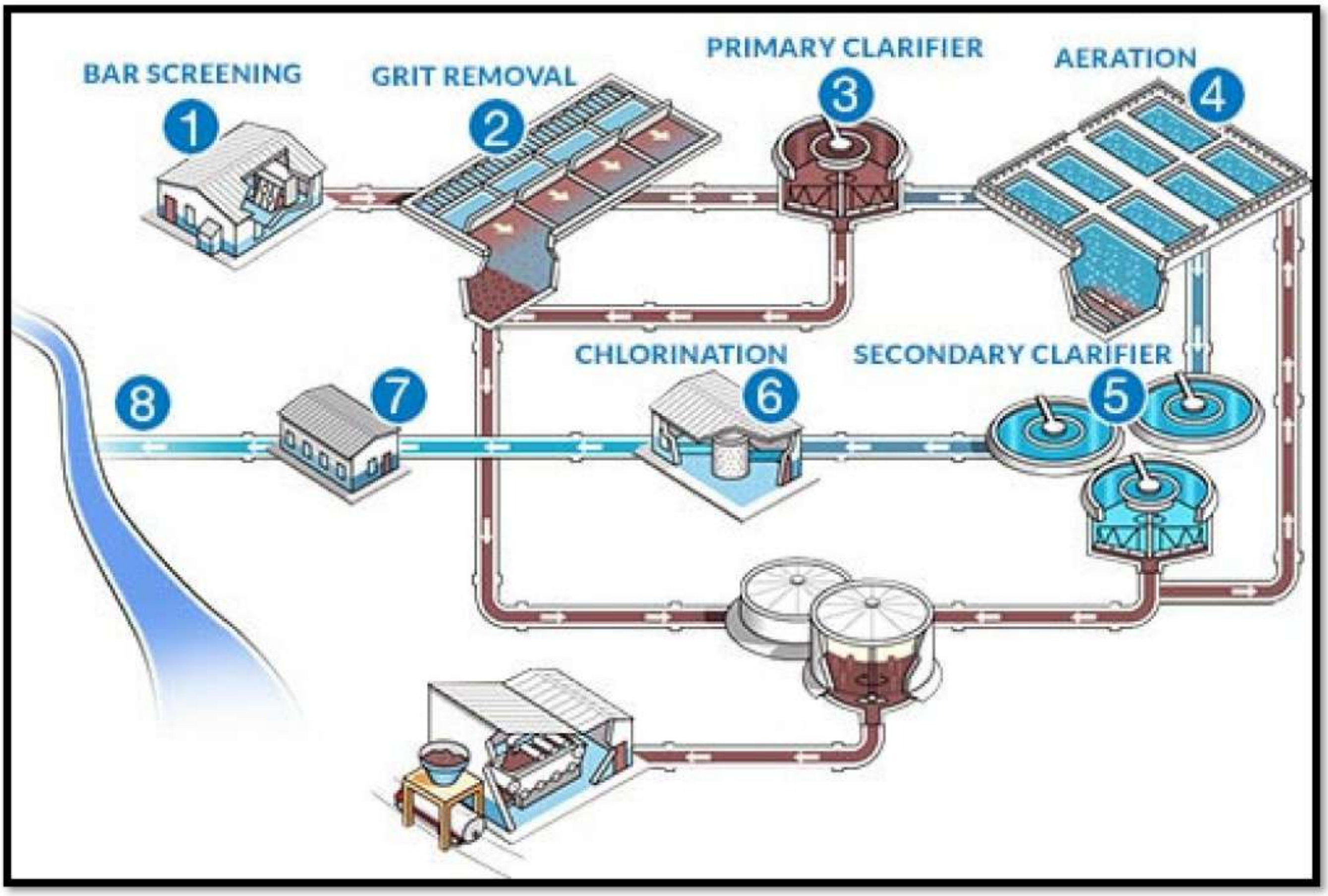

Figure 3. Eight Stages of the Wastewater Process.

Stage 1—Bar screening filters big particles from influents to protect facility equipment.

Stage 2—By passing the influent over or through a grit chamber, screening is used to eliminate the grift.

Stage 3—initial separation of solid organic materials from wastewater using a primary clarifier.

Stage 4—Aeration involves pumping air into the aeration tank to promote chemical precipitation conversion and supply oxygen for bacteria to continue growing and reproducing.

Stage 5—Pumping treated wastewater through a secondary clarifier enables any organic matter still present in the flow of treated water to settle out.

Stage 6—Chlorination (Disinfection). To eliminate any leftover bacteria in the contact chamber, chlorine is introduced.

Stage 7—Water testing and analysis. Testing to verify the water is flowing, clarifying, and aerating at the right rates and the optimum pH level.

Stage 8—Waste disposal. Clean water is discharged into the environment once it satisfies all permit requirements.

4.1.1. Primary Process

- Screening

Screening is considered the preliminary or pre-process to remove the larger solid waste present in the wastewater, such as wood, clothes, kitchen refuse, and others. The purpose of screening also is to separate the larger solid waste so that it will not cause any potential damage to the next process equipment, especially the pump and process that treat finer pollutants. The screen can be classified into three broad categories—coarse, fine, and micro. Hand cleaned coarse screen is normally adopted in the small treatment plant, whereas a mechanically cleaned screen, which is more efficient, is classified further into four types—chain-driven screen, catenary screen, reciprocating rakes, and continuous belt screen [62]

- Centrifugal separation

Using a decanter centrifuge (Figure 4), this method generates liquid-solid separation, sludge dewatering, and sludge thickening. The wastewater is applied to centrifugal devices and rotated at a different speed so that solids or sludges are separated and discharged according to their density [63]. Sludge discharge can be adjusted to suit its disposal requirements either in fluid condition for land application or as dry stackable cake (dewatered sludge) to reduce its weight and volume before transportation or disposal. The disadvantage of this method is it requires high capital cost and frequent maintenance since high horsepower motors are used.

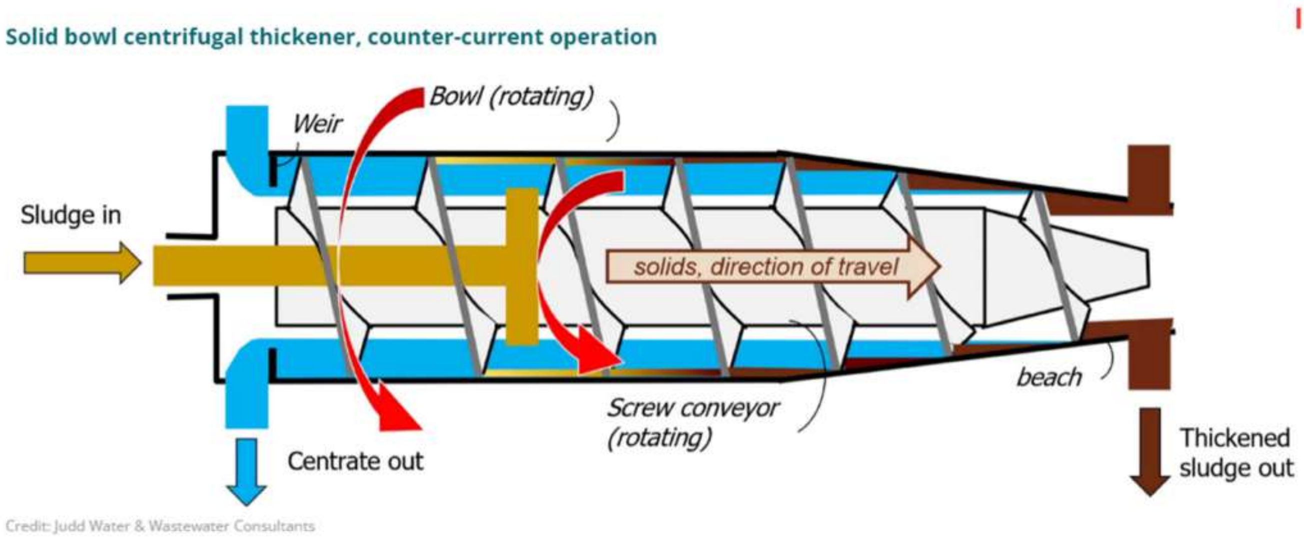

Figure 4. Decanter centrifuge operation.

Centrifugal separators are also widely used in the marine industry as an alternative option for the gravity separators that are used in the bilge water treatment (dirty water collected inside the bilges of the ship, which contains contaminants such as waste oils, oily wastes, lubricant, grease, etc. [64].

- Coagulation & Flocculation

Coagulation is the act of introducing a coagulant to destabilize a stabilized charged particle [65]. In contrast, flocculation is a mixing technique that promotes agglomeration and aids in particle settling through mixing duration and intensity management. The additional coagulant will cause a colloidal particle in the wastewater that is too small for gravity settling to lose charge [64]. Destabilization causes larger flocs to develop, which facilitates easier settling. One of the determining criteria for the procedure's effectiveness is pH, temperature, and contact duration.

The inorganic coagulants alum, ferric sulfate, ferric chloride, starch, activated silica, and aluminum salt are used often. These highly charged ions will neutralize the suspended particles when introduced to water. Short polymer chains are produced by the generated inorganic hydroxides, which promote micro-flocs' development. Most suspended particles may be removed using inorganic coagulants. Still, some organic precursors may also mix with chlorine to make disinfection by-products and produce significant amounts of floc, which can trap bacteria when they settle. As they consume alkalinity, inorganic coagulants have the potential to change the pH of water. As a result, corrosion-resistant feed and storage equipment is needed, and the settling floc needs to be disposed of in a way that does not harm the environment [66]. Here are a few instances of how inorganic coagulants react:

Ferric Sulfate

$$Fe_2(SO_4)_3 + 3Ca(HCO_3)_2 — Fe(OH)_3 + 3CaSO_4 + 6\ CO_2$$

Ferric Chloride

$$2FeCl_3 + 3Ca(HCO_3)_2 — 2\ Fe(OH)_3 + 3CaCl_2 + 6CO_2$$

ALUM

$$AL_2(SO_4)_3 + 3\ CA(HCO_3)_2 — 2AL(OH)_3 + 3CaSO_4 + 6CO_2$$

Along with conventional inorganic coagulants, polymers, often more expensive, can be utilized as coagulant aids. The efficacy of sedimentation and gravity separation is increased by adding synthetic cationic, anionic, and non-ionic polymers. To draw suspended materials and balance their surface charges, cationic polymers can be employed alone or in conjunction with alum or ferric coagulants, whereas anionic polymers are frequently utilized with metal coagulants [66].

- Floatation

The suspended solids, oils, greases, and other materials may be eliminated by adding air or gas to the flotation process. The solid will stick to gas or air and condense into agglomerates, which then collect at the water's surface and are readily skimmed off [67].

- Separation by gravity and sedimentation

Throughout this procedure, the wastewater is left undisturbed or semi-undisturbed for varying lengths of time in various types of tanks, enabling the suspended particles to fall to the bottom of the tanks under the force of gravity [68].

4.1.2. Secondary Process

This process involves biological wastewater treatment designed to degrade wastewater pollutants by the action of indigenous, water-borne microorganisms [69], either by aerobic or anaerobic treatment. In a reactor with a constant high concentration of microorganisms, wastewater is cycled. Most of the time, bacteria or fungi assist in the conversion of organic contaminants into substances like alcohol, glucose, nitrate, etc., and occasionally they also assist in the detoxification of inorganic material.

- Aerobic process

Activated sludge, lagoon, and pond-based treatments spray and surface aeration, aerobic digestion, and simple or aerobic septic tanks are examples of aerobic wastewater treatment systems [70]. This process normally occurs in the oxidation ponds and effectively removes BOD, COD, dissolved and suspended organic, nitrates, phosphates, etc. However, the disadvantage is that many bio-solids are produced and require further treatment and management. This process can be summarized as below:

$$\text{Organic matter} + O_2 + \text{Bacteria} \rightarrow CO_2 + H_2O + \text{Bacteria} + \text{By-products}$$

- Anaerobic process

Anaerobic decomposition will occur in wastewater if free dissolved oxygen is not present. Bacteria transform organic matter into simpler organic matter based on nitrogen, carbon, and sulfur by producing gases like nitrogen, ammonia, hydrogen sulfide, and methane. Biogas containing methane is obtained by anaerobic digestion and utilized for energy recovery [71]. This process can be summarized as below:

$$\text{Organic matter} + \text{Bacteria} \rightarrow CO_2 + CH_4 + \text{Bacteria} + \text{By-products}$$

- Encapsulation

The atmosphere contains large amounts of nitrogen gas in a very stable and non-reactive state. Although soils only contain little nitrogen in their reactive forms (ammonium, nitrite, and nitrate), nitrogen is crucial for plant development. The Haber-Bosch process, developed in 1909, is the primary industrial method used today to create ammonia by converting atmospheric N2 to ammonia (NH3) through a reaction with hydrogen (H_2) [72]. The manufacture of N-based fertilizers has aided the ability to produce more food and crops. Still, at the same time, it is excreted mostly as urea and NH^{4+} by human metabolism and dumped into the sewer.

Although the traditional activated sludge technique is seen to be an effective way to treat wastewater, one of its drawbacks is that it frequently takes a while for slow-growing organisms like nitrifiers and anaerobic methane producers to become caught by the system [73]. The effectiveness of this process also depends on a higher biomass concentration; however, municipal wastewater treatment produces an input stream with a relatively low biomass content that is greatly diluted.

Using immobilization methods like encapsulation or attachment can help with this. Both have greater solid-liquid separation, can sustain a high cell concentration, and are less temperature-sensitive. In encapsulation, cells are immobilized by ionotropic or thermal gelatine, which is applied to porous polymeric materials such as alginate, agar, polyacrylamide, carrageenan, cellulose acetate, and polyvinyl alcohol (PVA) [74]. Additionally, polymer gels, microcapsules, liposomes, hollow fibers, and ultrafiltration membranes are utilized in the encapsulation process [75]. PVA is the most popular material among the many options available since its physical stability (solubility, biodegradability, and diffusivity) and mechanical stability are unaffected. It can generate a lot more concentrated cell population and thus increase nitrification rates

4.1.3. Tertiary Process

In urban areas where the population is increasing, and water resources are constrained, wastewater may be a useful resource. The tertiary process' technologies may create water of high safety standards that can be utilized for human consumption, industry, medicine, etc.

- Oxidation/Advanced oxidation

Organic wastewater is often treated and hygienically cleaned using oxidations. The chemical oxidation technique uses substances that may oxidize pollutants and destroy organic molecules, such as chlorine, ozone (O_3), hydrogen peroxide (H_2O_2), Fenton's reagent (solution of H_2O_2 with ferrous iron as the catalyst), chlorine dioxide (ClO_2), etc. Ammonia, phenols, dyes, hydrocarbons, and other organic contaminants may be effectively removed with this technique [76].

The main advantage of this method is the organic contaminants are generally oxidized to CO_2. The single oxidation process may not be sufficient and efficient; hence, the combination of the few oxidation processes called advanced oxidation can be carried out simultaneously. Advanced oxidation is combined with ozone and peroxide, enhanced ultraviolet oxidation such as UV/Fenton, UV/ozone, and photocatalysis [77]. The drawback of this method is the cost is high since a continuous input of chemical reagents is required to maintain the operation of most of the system. It is not cost-effective to use oxidation methods solely to handle a large amount of wastewater; instead, they should be deployed in the final stage after primary and secondary treatments for disinfection purposes.

4.2. Adsorption

Organic pollutants can be eliminated from wastewater streams via adsorption [56]. Mass transfer processes like liquid-liquid, gas-liquid, gas-solid, or liquid-solid interfaces include adsorption. A technique for physically removing soluble molecules (adsorbate) from surfaces of solid substrates (adsorbent) [78]. Adsorption is a technique for removing organic pollutants from wastewater streams. Adsorption is a mass transfer process that can occur at a liquid-liquid, gas-liquid, gas-solid, or liquid-solid interface. A physical procedure wherein soluble molecules (adsorbate) are removed by adhesion to the surface of a solid substrate (adsorbent). The adsorbent should thus be activated before use. By using adsorption, a variety of organic compounds may be eliminated. Activated carbon is the most popular adsorbent and may be made from biomass [79]. The distinction between absorption and adsorption is seen in Figure 5. The most often used adsorbent is activated carbon, a kind of carbon that has been treated to produce numerous tiny, low-volume holes that increase the surface area accessible for adsorption [80].

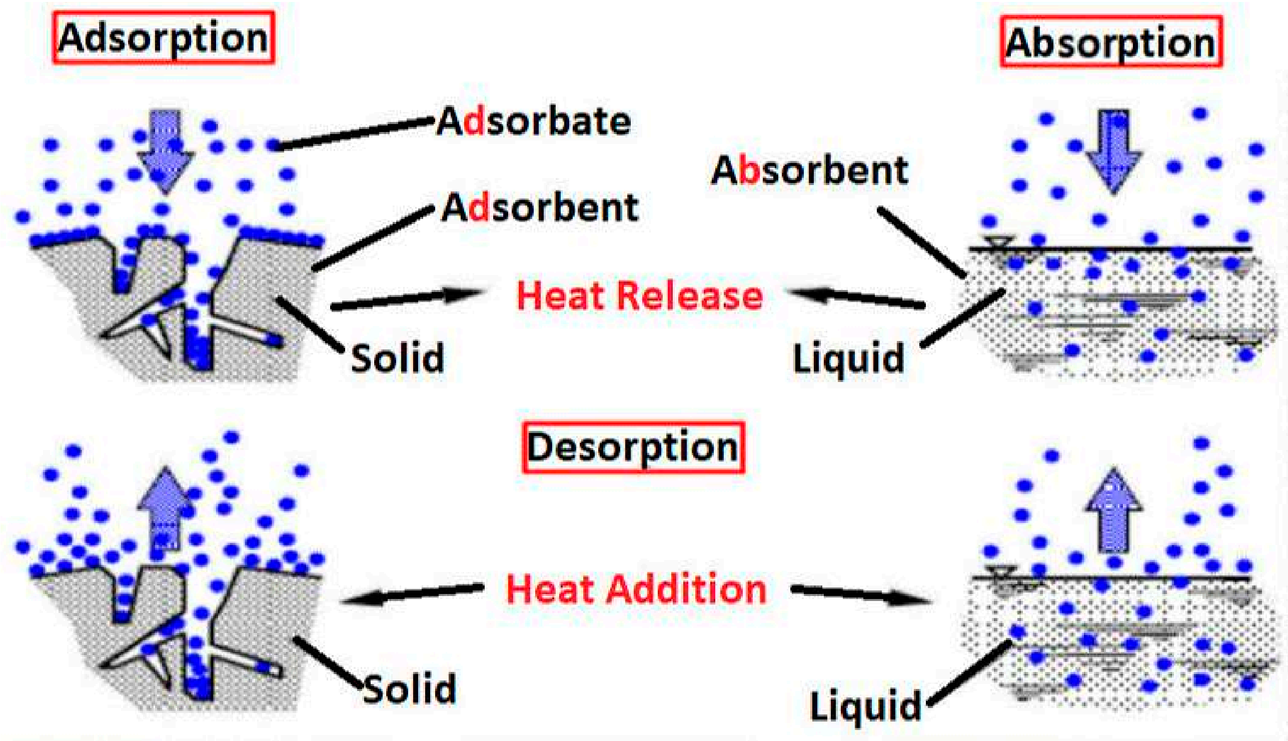

Figure 5. A comparison between absorption and adsorption [81].

Some factors affect adsorptions, (1) particle diameter, (2) adsorbate concentration, (3) temperature, (4) molecular weight, (5) pH, and (6) Iodine number [82]. The adsorption is directly proportional to the surface area and inversely proportional to the adsorbent's particle size, according to particle diameter. However, when the relationship between temperature and adsorption is direct, temperature is another component that influences adsorption. In addition, molecular weight is often inversely related to adsorption depending on the compound weight and the design of the pores used for diffusion control. Due to surface charge, adsorption is inversely proportional to pH [83]. It is challenging to compare the individual characteristics of adsorbent and adsorbate.

A molecular, atomic film (adsorbate) is formed when a liquid or gas solute accumulates on the surface of a solid or liquid (adsorbent) as a result of a surface phenomenon mechanism. A material or molecule adhering to the surface of another substance or adsorbent is known as the adhesion process. The adsorbent can be made of natural materials such as activated carbon, charcoal, clay, zeolites, and ores or artificial materials, including sewage sludge, household trash, industrial waste, and polymeric adsorbent [84]. Each adsorbent has unique properties, such as porosity, pore structure, and the type of surfaces it may adsorb from. In general, there are three different adsorption processes: exchange ion, chemical, and physical (stronger bonding and largely irreversible). Adsorption is regarded as one of the cost-effective and low-maintenance treatment options due to the local availability of the material and the fact that the process is temperature-dependent [7].

Adsorption filters away organic compounds, fluorine, chlorine, and radon. However, it is thought to be ineffective at filtering out inorganic, metal, and microbe forms of substances. However, recent nanomaterials such as carbon nanotubes and their composite have been developed and used to remove heavy metals and organic pollutants. Pre-filtration is required before adsorption because suspended particles and oils reduce the process efficiency.

Using this technique, contaminants that can be treated are organic pollutants, dyes from industrial wastes, and phenols, which are usually used to synthesize dyes, plastics, and pharmaceuticals used to make antiseptic and pesticide chemical industries [76]. Figure 6 shows the adsorption procedures of dye from wastewater. The regeneration of columns and column life is the main issue to be considered in this method.

Figure 6. Adsorption of dyeing wastewater [85], with permission from Elsevier.

The non-toxic ions from an ion exchanger, which may be either a cation or an anion and contains active sites on its surface, are exchanged with the hazardous ions found in wastewater. Low amounts of inorganic and organic materials are eliminated using this technique. Acrylic, zeolites, and sodium silicates are examples of ion exchangers [86].

4.3. Membrane Technologies

Several methods were used for the wastewater treatment technologies, such as coagulation-flocculation, biological treatment systems, and conventional filtration. Improvement from the existing water treatment technologies also meets the current discharge and reused standards. Membrane technologies are a major use in water treatment in this decade. According to Singh and Hankins [87], membrane technologies are the most economical and sustainable for wastewater treatment; this is because they do not use chemicals and are environmentally friendly, and are easy to use for all sectors. These membrane technologies are not a new invention because the efficiency and the effectiveness of using this make the wastewater have good quality.

A membrane is a selective style with two phases in the movement of components. Isotropic and anisotropic are two classifications of membranes [88]. Isotropic membranes are uniform in composition and physical structure. Anisotropic is non-uniform, consisting of different layers, forms, and designs. The material used in the membrane can be classified into two, organic and inorganic [89]. Organic membranes are made from synthetic organic polymers. Inorganic membranes are made from such materials as metals, ceramics, zeolites, or silica [90]. The membrane can be classified according to its bulk structure, morphology, and application Figure 7 [5].

The driving forces will move media through the membranes with different effects. The schematic diagram below Figure 8 summarizes membrane processes according to their driving forces. These are based on the membrane process, non-equilibrium and equilibrium, pressure, and non-pressure driven process.

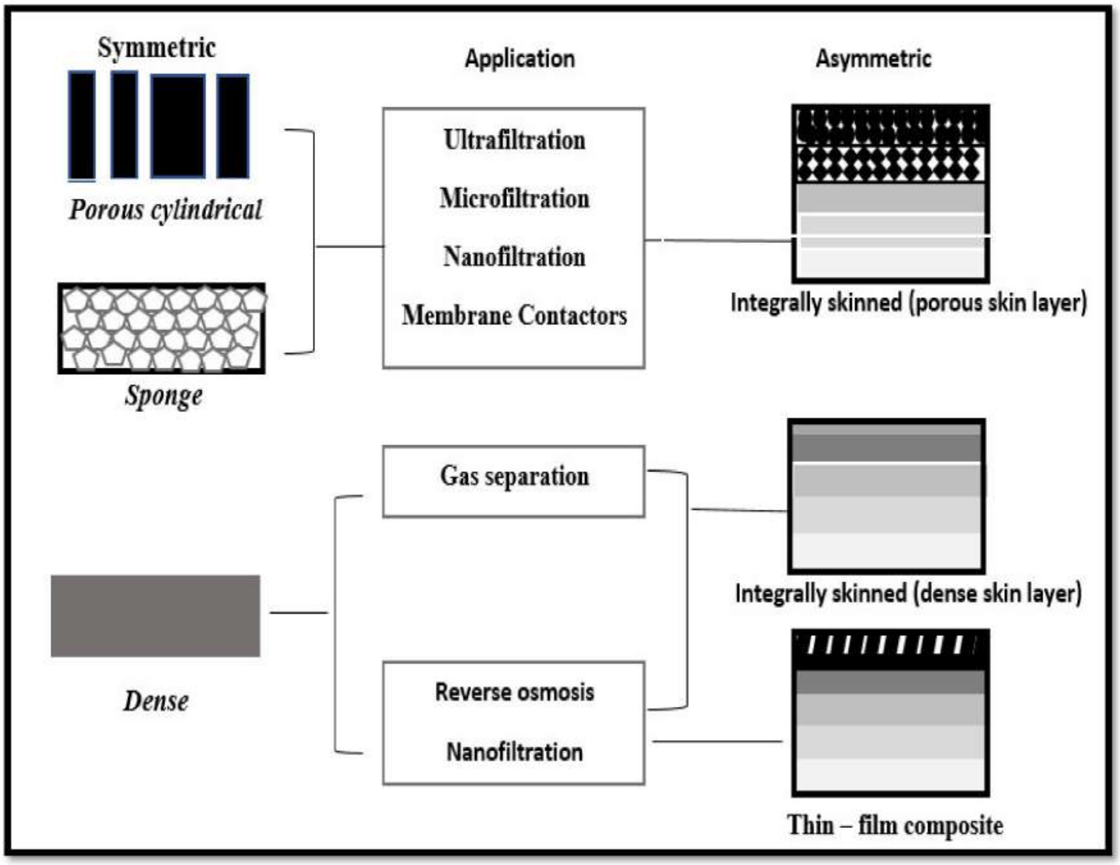

Figure 7. Membrane types are classified based on their bulk structure (symmetric or asymmetric), morphology (porous, sponge, dense, integrally skinned, thin-film composite), and application.

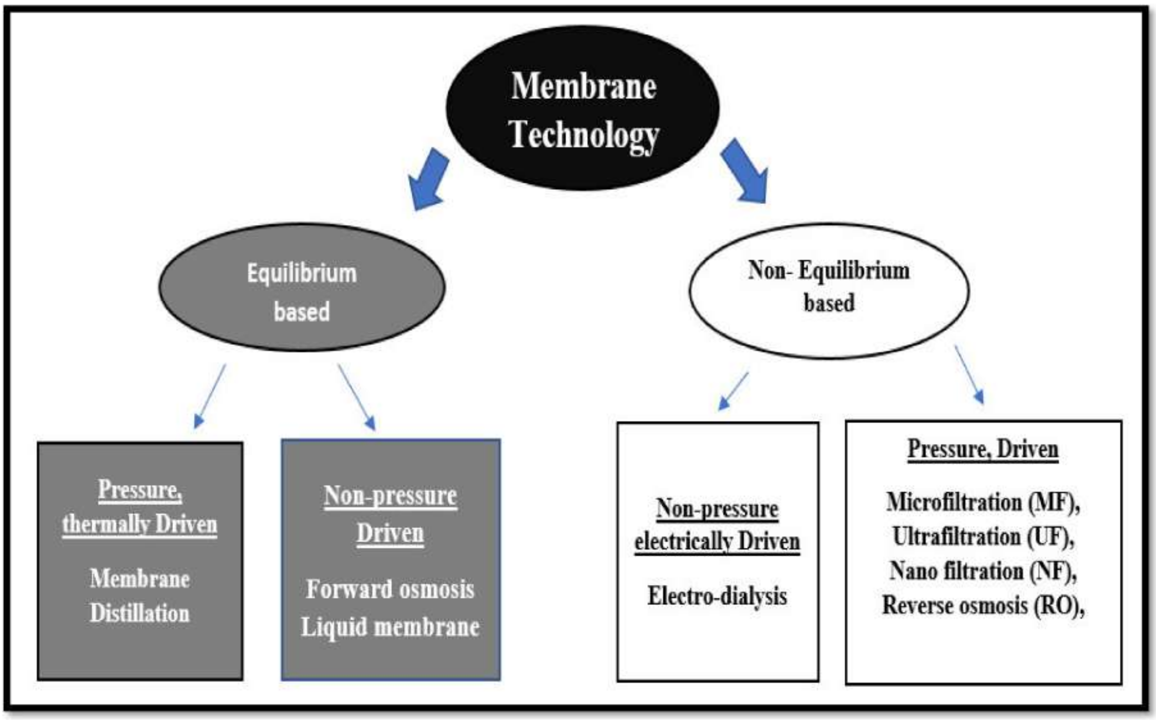

Figure 8. Some membrane processes are depicted schematically. Adapted from [91], with permission from Elsevier.

Above are five types of the membrane process, which are commonly used in water and wastewater treatment for non-equilibrium based:

- Micro and ultra-filtration.
- Membrane bioreactor (MBR).
- Reverse osmosis (RO).
- Electrolysis.
- Electrodialysis.

These methods can remove dissolved compounds and finely dispersed particles from liquids. Membrane transport, or the flow of solutes or solvents through thin, porous polymeric membranes, is at the heart of all five technologies.

- Micro and ultra-filtration

This method can remove particles of 0.04 to 1 μm [76] in size with the total suspended solids not exceeding 100 mg/L. The filters used are made of cotton, wool, rayon, cellulose, fiberglass, nylon, asbestos, etc., arranged in different arrangements or patterns and operate under a pressure of about 1–3 bar. Pre-removal of suspended solids is required for the long life of the filter.

- Membrane bioreactor (MBR)

This combines activated sludge with membrane filtration equipment, typically low-pressure microfiltration or ultrafiltration membranes [92]. In normally activated sludge facilities, the critical solid-liquid separation process is done using a clarified system instead. MBR system often comprises ten or eleven sub-systems and includes fine screening, the membrane zone, and some type of post-disinfection process (Figure 9). The membrane zone is the initial step in the biological process where microbes are used to degrade pollutants filtered by a series of submerged membranes. Air is introduced through integral diffusers to continually scour the membrane surface during filtration to facilitate mixing and contribute oxygen to the biological process [93,94]. The benefits of MBR have reduced plant footprint and higher quality of effluent, and it comes with a modular schematic that allows for flexible configuration [95].

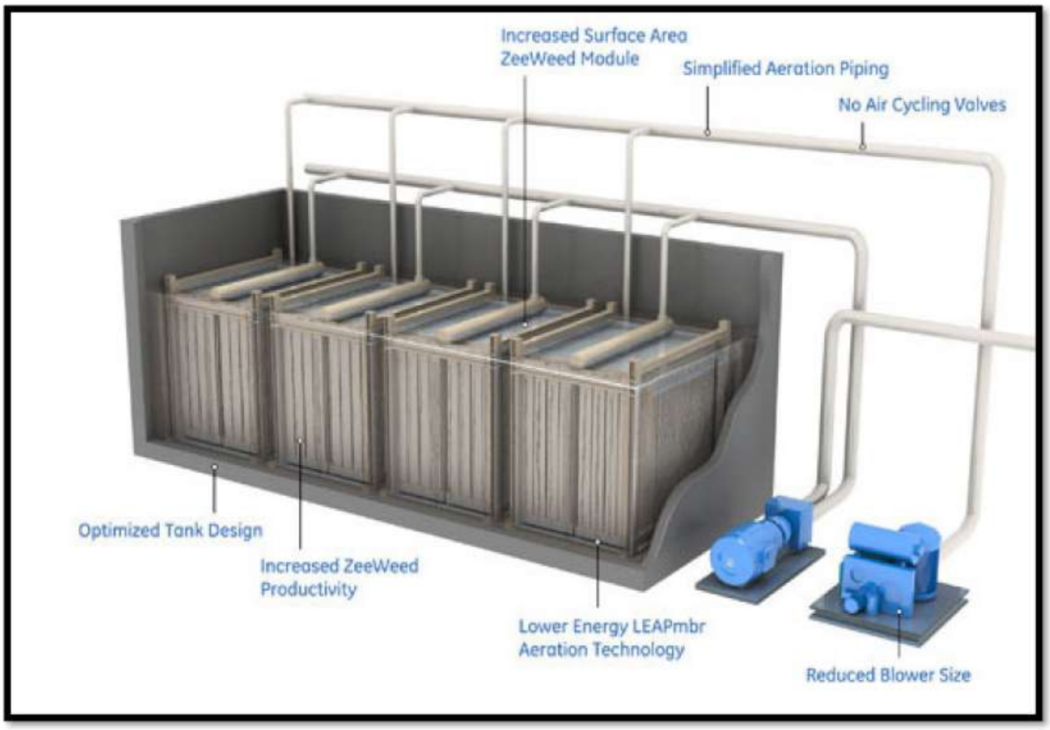

Figure 9. Membrane bioreactors for wastewater treatment [96].

- Reverse osmosis (RO)

This process, also known as hyper-filtration, may remove up to 99% of total dissolved solids, organic dissolved materials, bacteria, viruses, and other microorganisms since its filter pore width is smaller than that of micro- and ultra-filtration [76]. The membranes that are applied with pressure larger than the osmotic pressure include cellulose, polyether, and polyamide membranes that are structured in tubular, disc, spiral, and other shapes. RO is the most cost-effective method for producing potable water today from desalinated saltwater and salty water. Since RO systems are self-cleaning, do not use chemicals, and only power and high-pressure water, they require very little maintenance. To reduce the concentration of colloidal and dispersed particles, pre-treatment is also necessary. Reverse osmosis is contrasted with other membrane processes in Figure 10.

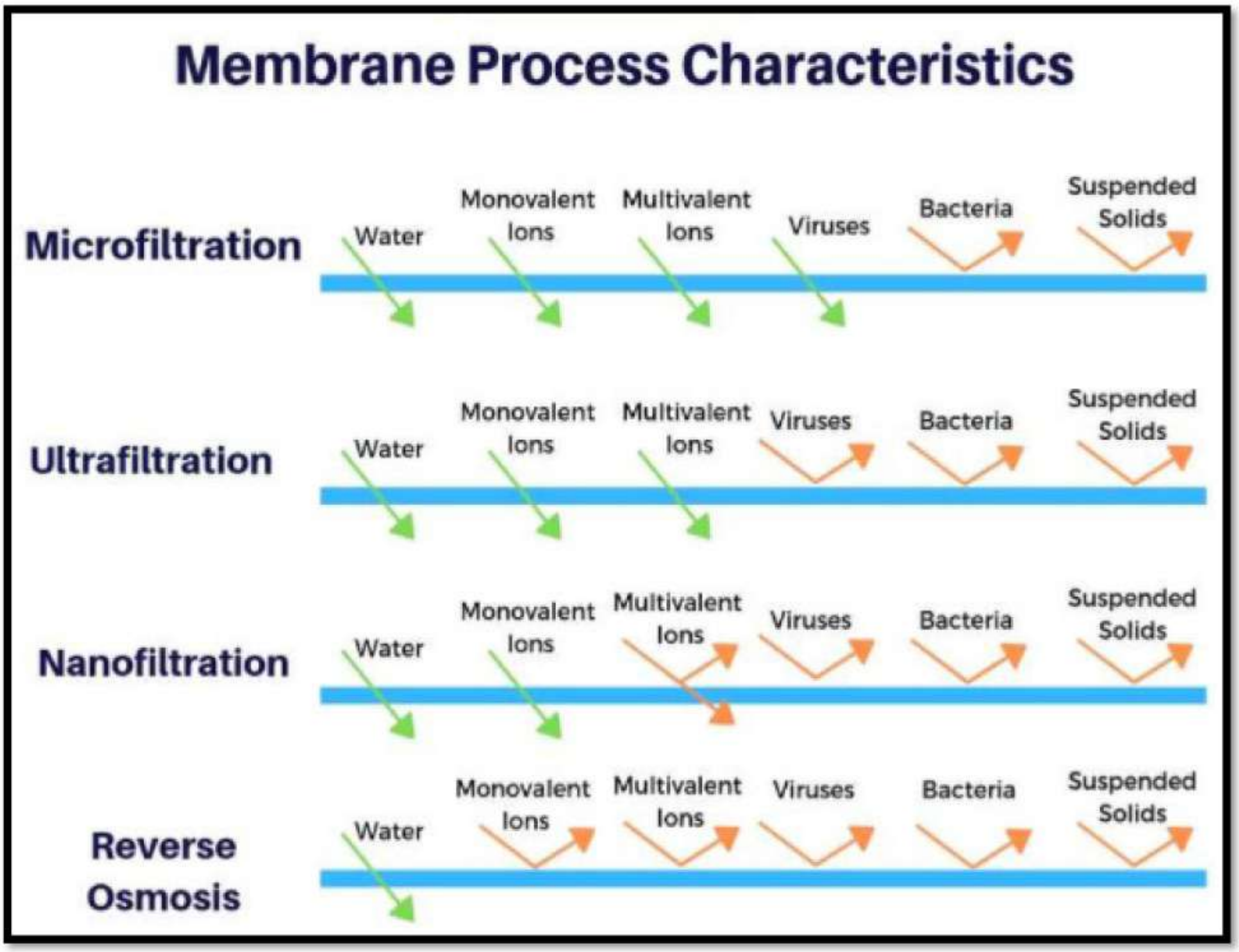

Figure 10. Comparison of membrane process characteristics.

- Electrolysis

Compared to conventional wastewater treatment processes, this approach is innovative and alternative. In the process of electrolysis, soluble substances either deposit on the surface of the electrodes or break down due to an electrochemical redox reaction. Most metal ions are deposited on the electrode surface while organics are broken down into CO_2 and H_2O or other low or non-toxic compounds. Due primarily to the present capital expense of its electrodes, this approach has not yet been fully applied to the wastewater treatment at the commercial level [97]. It is used to treat some industrial effluent, particularly those enriched with metal ions and organics. Additionally, Figure 11 displays the electrolysis processes used to cleanse wastewater sludge.

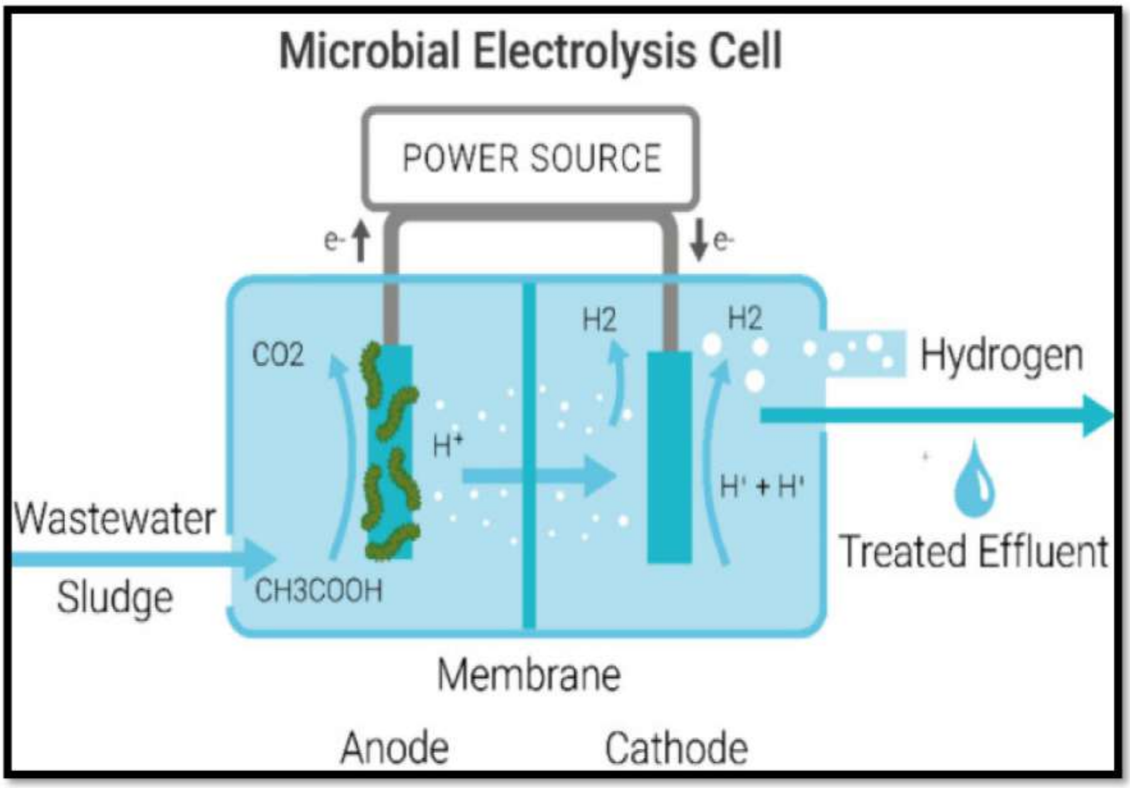

Figure 11. Electrolysis procedures for the treatment of wastewater sludge [97].

- Electrodialysis (ED)

The advantages of ED include high recovery and chemical-free functioning. Water, nutrients, salts, acids, and bases may all be recovered from the effluents of animal farms, desalination plants, and municipal wastewater treatment facilities [98]. The fundamental idea behind ED is that it is an electromechanical separation technique that supports ionic separation by utilizing an ion-exchange membrane as a dynamic force. It is primarily thought to be useful for removing ionic species, hardness, and organics from electrolytes (Figure 12). Electrical current travels through the ED stack while a power source charges an electrode. The cation moves to the cathode while the electrically charged anions of the feed solution go to the anode. The anion exchange membrane (AEM) blocks the passage of cations via the cation exchange membrane (CEM) and vice versa (Figure 13), which causes the concentration of salt in the concentrate compartment to increase and the concentration of salt in the dilute compartment to decrease [99].

The foundation of traditional sewage treatment is that it is difficult to recover nutrients as gas or waste sludge that is released into the atmosphere. The advantage of ED is that it may simultaneously minimize nutrient loading into water resources while increasing the availability of phosphorus and nitrogen through the process of nutrient recovery. Fouling, a key disadvantage to using membranes to recover nutrients from wastewater, is the problem with ED. The positive charges of the anion exchange membranes are strongly attracted to most of the colloids' and organics' negative charges, making the anion exchange membrane more susceptible to organic fouling [62,99].

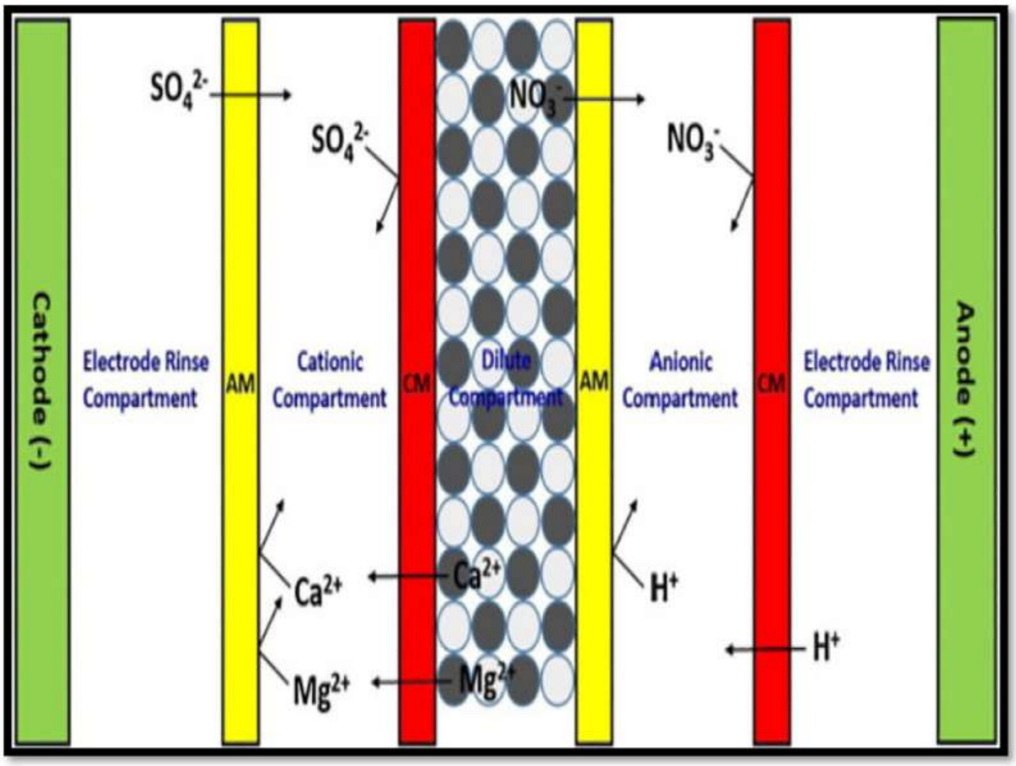

Figure 12. Schematic diagram of electrodialysis [100], with permission from Elsevier.

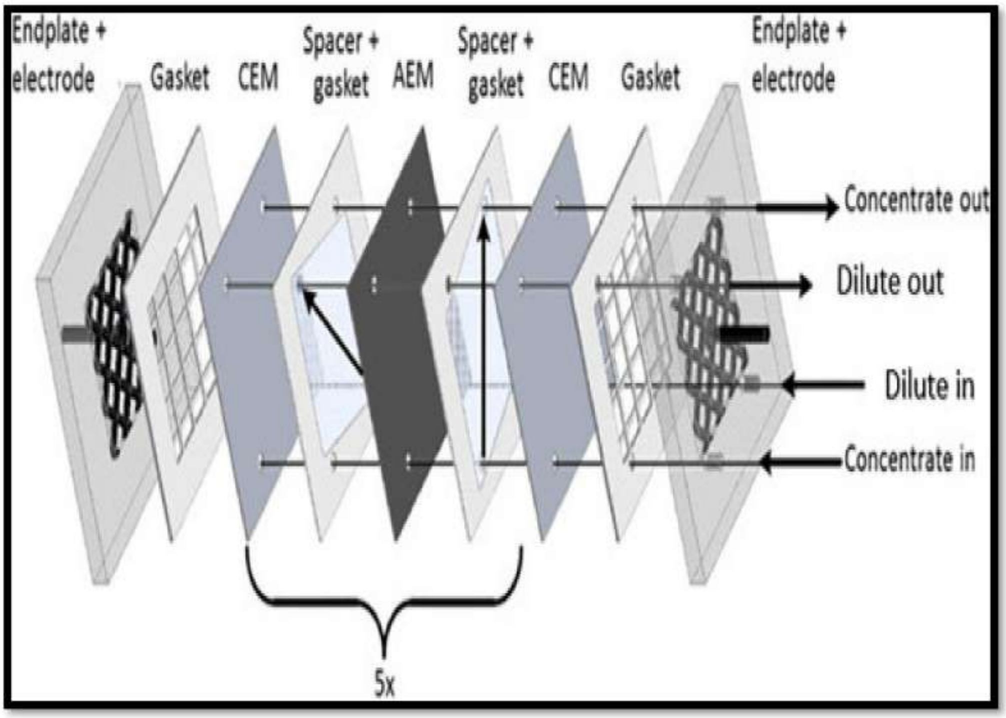

Figure 13. Electrodialysis stack with five cell pairs of AEM CEM [101], with permission from Elsevier.

4.4. Artificial Intelligence Models to Treat the Wastewater

These applications discussed wastewater treatment from different perspectives. Each perspective has its weaknesses and strengths. Moreover, Figure 14 illustrates journals with many published articles on artificial intelligence models for wastewater treatment. As a result, the most prolific publications on this subject are water science and technology, environmental modeling & software, and lecture notes in computer science.

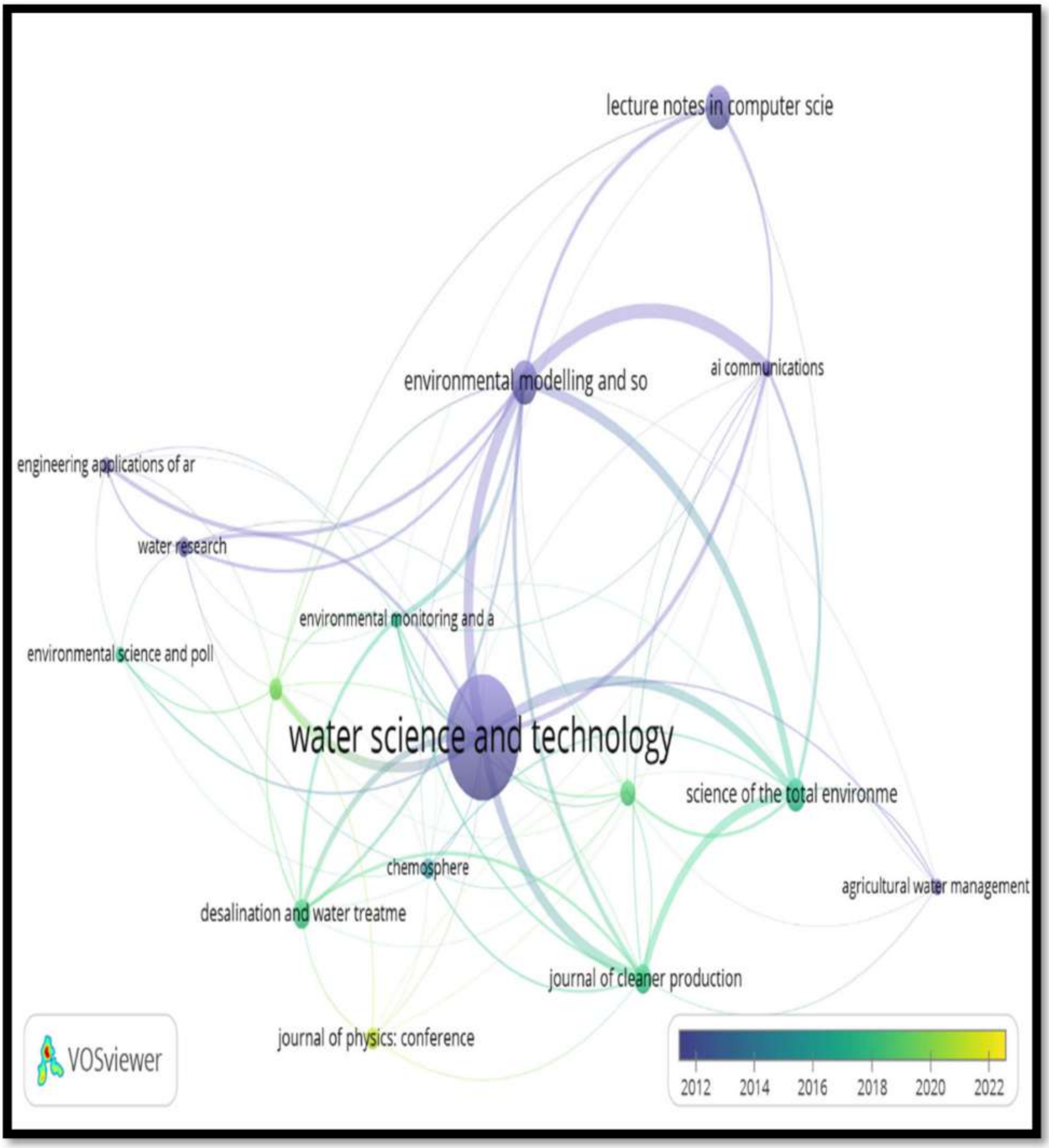

Figure 14. Journals with significant numbers of artificial intelligence models for wastewater treatment articles generated using VOSviewer. VOSviewer network visualization map of Journals using the keyword "artificial intelligence models for wastewater treatment," data collected from Scopus between 2012 and 2022.

On the other hand, Figure 15 shows which countries are performing the most research on artificial intelligence models for wastewater treatment. The United States topped the list, followed by Spain, China, Iran, and Italy.

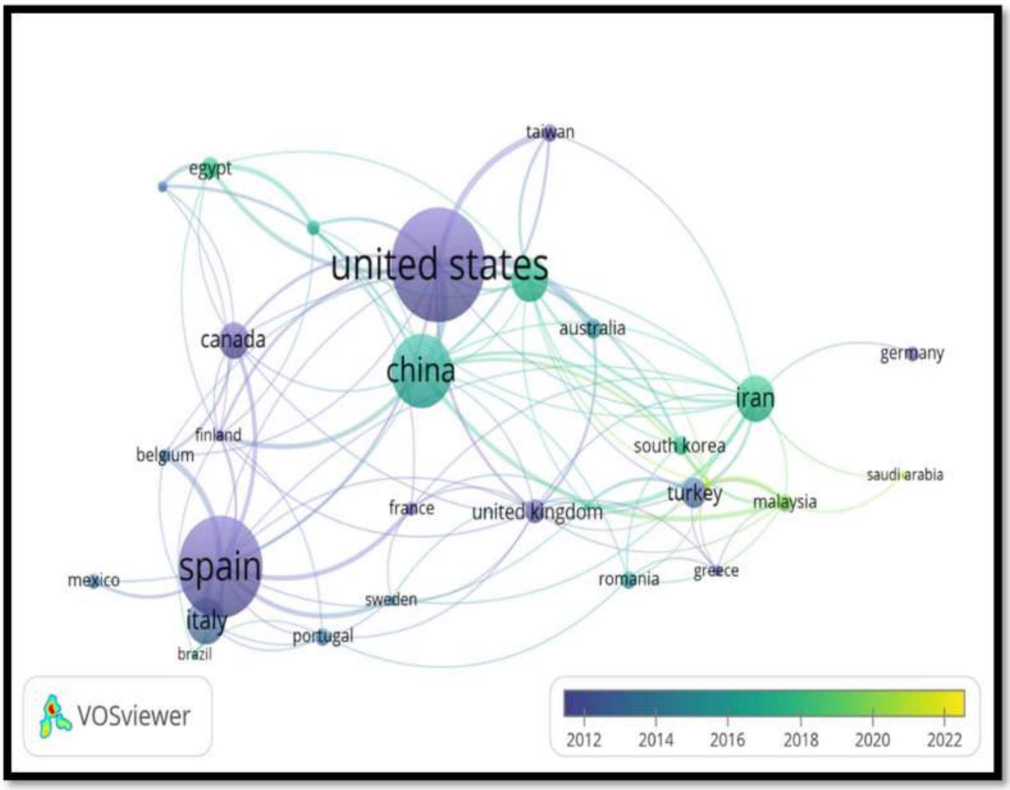

Figure 15. Network of relationships between countries with research teams. Source Data from the Scopus between 2012 and 2022. VOSviewer network visualization map of the top producing countries for "artificial intelligence models for wastewater treatment" research.

Nevertheless, several applications of artificial intelligence (AI) in wastewater treatment have been developed in the literature, as shown in Figure 16.

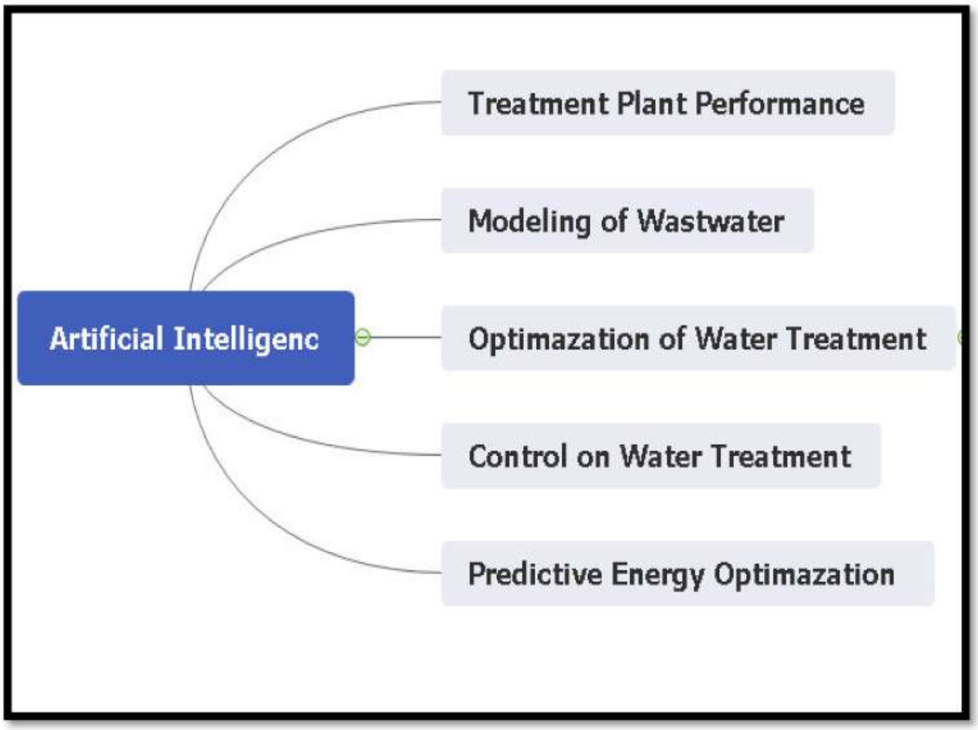

Figure 16. Applications of artificial intelligence in wastewater treatment.

In the wastewater treatment process, artificial intelligence (AI) could be employed to minimize complexities [102]. AI is applicable to predicting the performance of water treatment, designing the sensors that estimate key components, optimizing the operating parameters, evaluating the effluent quality, designing the treatment units, optimizing the micropollutants and other emergent pollutants, predicting maintenance strategies using fault diagnosis, optimizing the energy efficiency of treatment processes, operating instructions based on performance, and making the systems fully automated. During the past few decades, the use of AI-based models in wastewater treatments has caused an increase in manifolds. Every intelligent controlling method has its weaknesses and strengths. To achieve the best outcomes, these methods must be chosen considering the treatment system mechanism and the aim for which they are employed [103].

The present study investigates the application of different models to wastewater treatment by searching the Scopus database with the following keywords: 'wastewater treatment,' 'Artificial Intelligence, and the model's name. In recent years, several soft computing tools and approaches in machine learning [104–110] and artificial neural networks (ANNs) [104,111–114] have been applied to the prediction of water quality and associated variables. In brief, ANNs process the information; these systems involve data computation as input and output.

ANN can assess the wastewater treatment process by evaluating variables such as BOD, COD, and total suspended solids (TSS). Esquerre et al. [115] used the BOD determination approach by applying the multilayer network and link networking analysis method to the wastewater biological treatment units (lagoon). In other studies, Akratos, et al. [116] and Hamed, et al. [117] introduced a new ANN-based model applicable to the BOD removal process. Nourani, Elkiran and Abba [104] compared three different models in terms of evaluating a wastewater treatment facility's performance, considering variables such as TSS, BOD, and COD. Their findings confirmed that the ensemble neural network model outperformed the others regarding the reliability in the prediction of BOD (24% increase) and COD along with total nitrogen in the effluent (around 5% for both). In the same way, the BOD values of a highly-eutrophic river were predicted by employing a computational modeling system. Based on the obtained results, the parameters could be predicted beforehand with the use of 16-4-1 modelling with employing phosphate as one of the essential input variables [118]. The role of AI could play in modelling in the degradation process of penicillin-type antibiotics (i.e., amoxicillin, cloxacillin, and ampicillin) within an aqueous medium by a Fenton procedure known as COD removal. The results obtained by ANN showed a high correlation coefficient, which revealed that the model was successful. The following factors impacted the COD removal: time, pH, concentration, and the molar ratio of hydrogen, peroxide, and ferrous ions [119]. The estimation of COD removal efficiency in the case of sewerage water was investigated using ANN [30]. In a case study, Samaneh et al. evaluated the performance of the Khorramabad wastewater treatment facility using AI. They considered the influent characteristics such as pH, temperature, dissolved oxygen, BOD, and COD dissolved solids, and the output performance was examined regarding COD, BOD, and total solids. They achieved acceptable correlation coefficients with maximum contaminant removal efficiency of 87.68%. Zaqoot et al. utilized an ANN-based linear regression model in order to determine the water quality parameters. The authors considered some influent values such as temperature, pH, COD, BOD, and TSS. The findings revealed that ANN better evaluated the wastewater's performance than the linear regression; this result was also confirmed by the error analyses and regression coefficient values [111]. In another project, a hybrid approach was used by Zhu to predict the BOD concentrations. Combining the connectionist systems, regression analysis, and goal programming caused a decrease in the overall accuracy of the approach used, but it demonstrated good BOD concentrations predictably [112]. In [120], the researchers used AI to examine how operational conditions affect the exclusion of chemical oxygen demand from olive mill waste effluent. They performed several experiments to check the impact of pH, process time, and electricity flowing per unit cross-sectional area upon the chemical oxygen demand removal efficiency. They found that the chemical oxygen demand deduction's predicted effectiveness was equivalent to the experimental results (42.7%), with an R^2 value of 0.92.

Zhang, et al. [121] proposed a novel hydraulic model to predicate the sewer flow using long short-term memory (LSTM) through time series, which obtain accurate results that help sewer management. In the same way, Kang, Yang, Huang and Oh [114] used bi-LSTM (bidirectional long short-term memory) to the wastewater flow rate in a practical sense with data collected for training for 31 days around 4464 for both tanning and validation. Mamandipoor, et al. [122] proposed methods for automatic wastewater fault detection using LSTM without human intervention. They used real-life datasets collected from around 5.1 million sensors and then applied statistical analysis methods, machine learning classifier, specifically, support vector machine (SVM), and LSTM. The proposed model performance is evaluated in term recall reached ninety-two% using LSTM. Similarly, Mateo Pérez, Mesa Fernández, Villanueva Balsera and Alonso Álvarez [115] developed a method to predicate fats, oils, and greases in wastewater. They used SVM; the model recorded 98.45% in training and 72.73% in evaluation. Moreover, Zhuang, et al. [123] used a hybrid model consisting of CNN and LSTM, the extraction process of the features from data of the sequence of the water quality performed in the first phase, which is the CNN, while the predication in the second phase, which LSTM after obtaining the input from the first phase. In using reinforcement learning, Granata, et al. [124] focus on optimization strategy in the papermaking process for treating the wastewater based on simulation of the natural environment. Barzegar, et al. [125] focus on the quality of water indicators based on the four factors: TSS, TDS, COD, BOD using the dataset from different areas with 3765. Then, they used two machine learning classifiers: support vector regression and regression trees. The results show that support vector regression is better than regression trees.

Numerous specific AI models, methods, and tools have been proposed to solve specific wastewater treatment scenarios through this survey. These models have various redundant processes, concepts, methods, activities, and tasks, making applications of artificial intelligence in wastewater treatment unstructured and complex among domain practitioners. Therefore, a structured and unified framework is lacking to facilitate managing, sharing, and reusing artificial intelligence applications in wastewater treatment. Therefore, this study suggests a high abstract model organizes, unifies, and structures artificial intelligence applications in wastewater treatment among domain practitioners. This aims to identify, recognize, extract and match different processes, concepts, activities, and tasks from various applications of artificial intelligence in wastewater treatment in a developed high abstract model, thus, allowing domain practitioners to derive/instantiate solution models easily.

Furthermore, the impacts and optimization of operational parameters on heavy metal removal efficiency are described in Table 5. These operating factors primarily include starting concentration, temperature, pH, and adsorbent dosage. In addition, the various removal technologies for heavy metal removal and their possible adverse effects on the surrounding environment need to be discussed to enable a significant and influential choice to be made to reduce the potential for adverse health effects and boost the effectiveness of heavy metal removal [126]. The selection of the most effective technologies, on the other hand, might be difficult since each approach has its own unique set of criteria. Therefore, strategies that are friendlier to the environment and more sustainable are quite important. Consequently, sustainable treatment methods and an efficient method for improving heavy metal removal from wastewater are approaches that do not generate secondary environmental contamination, consume less energy, and are more cost-effective. In addition to this, sustainable treatment methods are also environmentally friendly. In addition, more studies are needed to establish the most effective ways for heavy metal removal efficiency using artificial intelligence while maintaining the same adsorption circumstances. This is necessary to anticipate the removal with a high level of accuracy.

Table 5. Comparative evaluation of different adsorbents and methods for heavy metal removal under different operational parameters.

Methods	Adsorption Conditions				Heavy Metal	Removal Capacity	Reference
	Concentration	Temperature °C	pH	Dosage			
Iron oxide/nano-porous carbon magnetic composite	5 mg/L	Room	8	1.8 g/L	As (III)	6.69 mg/g	[127]
Polymer-based hydrated iron oxide adsorbent	50 mg/L	Room	7	100 mg/L	As (V)	71.5 mg/g	[128]
Graphene oxide supported nanoscale zero-valent iron	5 mg/L	22 ± 2	3–9	0.43	As (III)	36 mg/g	[129]
γ-Al_2O_3	100	25	4	0.5	As (V)	54 mg/g	[130]
Fe/AlO(OH)	150 ppm	Room	3	1 g	As (V)	102 mg/g	[131]
Natural laterite from Thach That (NLTT)	200 µg/L	30	2–9	2.5 g	As (V)	580 µg /g	[132]
Tea fungal biomass	1.3–0.9 mg/L	30	7.2	20 g/L	As (V)	76%	[133]
Functionalized nanocrystalline cellulose	50 mg/L	7.5–2.5	Room	0.5 g/L	As (III)	10.56 mg/g	[134]
B. cereus strain ZS2	80 µM	30	7	0.5 g/L	As (III)	153 mg/g	[135]
Yersinia sp. strain SOM-12D3)	6.5 mg/L	30	7	0.5 g/L	As (III)	159 mg/g	[26]
Chemical precipitation (CaO)	32 mg/L		9–10		Zn^{2+}	99%	[136]
Membrane (RO)	500 mg/L	Operation pressure 5 atm			Ni^{2+}	99.5%	[137]
Aspergillus fumigatus (Dead)	10 mg/L	28	5	0.04 mg/L	Pb (II)	102 mg/g	[138]
Aspergillus fumigatus (Dead)	10 mg/L	28	5	0.04 mg/L	Cd (II)	120 mg/g	[138]
Poly(vinylbenzyl chloride)	160 mg/L	room	7	14 mg	Cu^{2+}	263.15 mg/g	[139]
Dried Watermelon Rind	400 mg/L	30–40	8	1.5 mg/L	Zn^{2+}	25 mg/g	[83]

5. Conclusions

In summary, water resources are very important for humans and all living things on earth. While water resources take up most of the earth, the exponential growth of population, livestock and food demand increases, and rapid industrial and urbanization cause restraints on the freshwater supply. The entire globe is having a water quality crisis due to unstoppable development growth.

The growth in world population, urbanization, and industrialization is increasing with a proportionate growth in wastewater generation and water consumption. This makes it important to have a complete well-functional waste treatment system to protect our limited water resources and environment. As discussed, different methods and technology with their pros and cons shall be considered in designing a unique, efficient, cost-effective, and environmentally friendly treatment facility to serve its purposes.

In addition, given that wastewater is rich in nutrients and contains other useable chemicals, the wastewater treatment plant also plays an additional role as one of the resource recovery facilities, not just the former role as a mere pollution mitigation entity. Newer technologies and approaches must continue to be studied and improved to create a more sustainable system to benefit mankind and protect our planet.

Furthermore, the water issues' main cause is the lack of focus and comprehension of water management and wastewater treatments. This action poses greater threats as, daily, human activities are degrading the quality of fresh water. Urban water pollution is mostly caused by anthropogenic activities, which are very concerning because it is a common behavior in daily life.

Modern agricultural activities are no less threatening to the ecosystem and environment. The widespread usage of fertilizers and pesticides has deteriorated the soil. When the water runoff goes into the river, the water is most likely to be contaminated with the residue of chemicals from using fertilizers which encourage algae growth. The dying algae promote bacteria growth in rivers, threatening the river's aquatic lives.

Industrial activities also cause a lot of water pollution, especially in the petroleum industry and radioactive industries. Both industries produce dangerous wastewater if they are not treated and managed properly. The chemicals release toxic waste that can endanger all living things on earth.

In conclusion, it is important to have proper wastewater management and treatment. Both centralized and decentralized systems of water management can benefit the environment. Authorities have to plan the system according to the surroundings to have good results for wastewater management. Overall, the public also needs to participate in improving water and wastewater management.

Author Contributions: W.A.H.A., Conceptualization, Data curation, Formal analysis, Resources, Visualization, Writing—original draft, Writing—review & editing; S.S., Supervision, Resources, Conceptualization, Project administration, Funding acquisition; N.O., Data curation, Formal analysis, Resources, Visualization; T.A.E.E., Conceptualization, Data curation, Formal analysis, Funding acquisition; W.M.S.Y., Resources, Data curation, Visualization, A.A.-D.; Software, Validation, Resources, C.Y.S.; Writing—original draft, Data curation, Validation, Funding acquisition; I.B.Y., Writing—original draft, Resources, Data curation, Visualization; N.A.N.b.C.R., Writing—review & editing; M.A., Investigation and Formal analysis; A.A., Investigation and Formal analysis. All authors have read and agreed to the published version of the manuscript.

Funding: Deanship of Scientific Research at King Khalid University through Large Groups (Project under grant number (RGP.2/49/43)). Ministry of Higher Education Malaysia (MOHE) and Universiti Teknologi Malaysia (UTM) project funding (UTMFR Grant No. 21H22) and the Post-Doctoral Fellowship Scheme under Universiti Teknologi Malaysia (UTM) Professional Development Research University Grant (06E27).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors fully acknowledged the Deanship of Scientific Research at King Khalid University for funding this work through Large Groups (Project under grant number (RGP.2/49/43)). The authors extend their appreciation to the Ministry of Higher Education Malaysia (MOHE) and Universiti Teknologi Malaysia (UTM) for project funding (UTMFR Grant No. 21H22) and making this important research viable and effective. Moreover, Wahid Ali Hamood Altowayti extends his gratitude to Universiti Teknologi Malaysia (UTM) for financial sponsorship and the Post-Doctoral Fellowship Scheme under UTM Professional Development Research University Grant (06E27).

Conflicts of Interest: The authors declare no conflict of interest.

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