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(Review Article)

Pollution and treatment of industrial waste water

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Abstract

Every year, a massive amount of wastewater is discharged into water bodies from various industries, and numerous processes are used to treat wastewater to reduce the number of pollutants. Industrial wastewater can be very different from sewage in terms of its discharge patterns and compositions. The overall scenario is not different for Bangladesh a developing country. Hence, the industrial wastewater treatment process has undergone modification as time passes newly discovered dangerous substances in the industrial wastewater treatment process worldwide. Multiple methods including conventional and advanced methods are upheld in this present paper with advantages and disadvantages also illustrated there. Besides, the potential for integrating two or more technologies to enhance treatment efficiency is also addressed. Considering low cost as well as maintenance purposes, among all the methods, hybrid or integrated technologies are found effective to reduce the contamination level of wastewater.

Keywords: Wastewater; Pollutants; Treatment methods; Ion exchange; Advantages and disadvantages of available methods; Wastewater management

1. Introduction

By definition, water is an inorganic, transparent, tasteless, odorless, and nearly colorless chemical substance. Water is the main constituent of earth's hydrosphere and the fluids of all known living organisms. It is vital for all known forms of life, despite providing neither food, energy, nor organic micronutrients. According to the biologists, all forms of life came from water. We are living on this planet due to the blessing of water. For important purposes such as drinking, bathing, watering animals, and irrigating lands, humans have been using water from the dawn of civilization to till now. However, this limited resource means a source of life under threat from the population, chiefly generated by human factors. Almost 71% of the earth's total surface is covered with water, only 2.5% of this amount can be considered freshwater [1]. It has been noted that 21 out of 37 largest aquifers have already crossed their sustainability tipping points [2]. The situation of water shortage, as well as stress, will be going downward gradually. In recent times, the economic water shortage problem is faced by 1.6 billion people at least one month a year. Water scarcity is a common phenomenon for two-thirds of the world's population [3]. It is explored that 1.8 billion people will be living in countries or regions that may face water scarcity, and two-thirds of the world's population could be living under water-stressed conditions [4]. These limited water resources are under threat from pollution regulated by human factors i.e., the agricultural sector, industrial production, mining, power generation, and other factors, etc. But it is needless to say that, the majority of the water sources, chiefly surface water bodies, however, are polluted because of industrial growth; urbanization, and man-made problems [5]. Pollutants make our surroundings hostile and lead to alarming conditions for human beings and welfare [6]. The overall scenario is not different for developing countries like Bangladesh. With over 12 million people residing in an area of 815.8 km2, rapid urbanization is increasing the size of Dhaka City both geographically and racially. Pollutants such as heavy metals, organic compounds, macronutrients, micronutrients, organic micropollutants, and microorganisms through industrial wastewater disperse into water bodies [7]. As the right

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of people to access suitable drinking water must thus be seen as a global issue the solution of which is dependent majority on industrial wastewater treatment leads to protect our environment from pollution.

2. Current status of water quality

Undoubtedly, Water is an indispensable substance of the earth that has much to do with its uniqueness of the earth. Without it, there will be no life on this planet. As the twentieth-century American philosopher, Loren Eisley put it, there is magic on this planet and it is contained in water. But it the sad to say that water also acts as an effective medium to transmit diseases. Globally 80% of diseases and 50% of the child at present time are strongly related to poor water quality. Every year around 829,000 people die from diarrhea because of unsafe drinking water, sanitation, and hand hygiene whereas children under the age of five are 300000 presenting 5.3 percent of all deaths in this age group. It is noticeable that the percentage of people who drink municipal water directly is greater than those of the people who use desalinated and household-filtered drinking water. A comparative study explores that tap water, purified water, and bottled water, tap water are essential sources of gastrointestinal disease. Moreover, the incidence of diseases such as cholera, trachoma, schistosomiasis, and helminthiasis is increased only for a lack of water and sanitation services. In the case of developing countries data from different studies provide clear evidence on the circle of cholera and contaminated water, and household water treatment and storage can reduce cholera. Gastrointestinal illness generated from disease, unsafe drinking water, and poor environmental hygiene inhibits nutrient absorption and malnutrition which is especially pronounced for children [8]. The scenario is mostly the same for Bangladesh as like third-world countries even though here water is available for 97% of the total population but the water quality is always debatable. Bangladesh is a riparian country having around 230 large and small rivers across the country. But the pollution that has been brought on by human activity has now strangled this water. Groundwater also loses its safety behavior since the high level of arsenic contamination in Bangladesh. The tubewell is only the source of drinking water for 97% of the total population in rural areas so in the first decade of the millennium 35 to 77 million people have been affected by arsenic. Water, sanitation, and hygiene-related issues cause 8.5% of the total death in this country. These above incidents have happened only when pure water becomes polluted whereas pollutants derived from different sources i.e., agricultural sector, industrial production, mining, power generation, or other factors ultimately affects human in general. But industrial growth, urbanization, and man-made problem are the main culprit for this water pollution mostly predominantly surface water [5].

Physicochemical properties parameters in Bangladesh standards especially for drinking purposes and industrial effluent are mentioned below in Table 1.

Table 1 Different parameters for drinking water and industrial effluent

Sample	BOD (mg/L)	COD (mg/L)	DO (mg/L)	Temperature (C)	pH	TDS (mg/L)	Conductivity (µ-mhos/cm)	Reference
Drinking Water	2	4.0	6.0	20-30		1000		[5]
Industrial effluent	50	200	4.5- 8.0	40-45	6-9	2100	1200	[5]

3. Wastewater and Wastewater treatment

Wastewater mainly refers to the utilized water mixed up with water from residential, mechanical, business or farming exercises, surface overflow or stormwater, and any sewer inflow or sewer penetration etc. It is essential to take into account non-conventional water sources to meet the growing demand for freshwater due to global water crisis challenges. Wastewater is seen to be an excellent alternative to choose from when there is a shortage of water due to various factors. But because there is such a wide variety of wastewater sources, which can include both organic and inorganic materials, it is necessary to periodically monitor the water's state to assess any potential risks to the environment as a whole. Besides satisfactory recycling of wastewater is urgent to care for public health. There are many kinds of wastewater and their treatment is depended on the type of wastewater and its characteristics [9].

3.1 The objective of wastewater treatment

3.1.1 Reduction of biodegradable organic substances in the environment

Organic substances present in wastewater such as carbon, nitrogen, phosphorus, sulfur, etc need to be broken down by oxidation into gases that are either released or remain in solution.

3.1.2 Reduction of nutrient concentration in the environment

From wastewater nutrients such as nitrogen, and phosphorus enrich water bodies or render it eutrophication process leading to the growth of algae and other aquatic plants which causes oxygen depletion in water storage and hampers aquatic life.

3.1.3 Elimination of pathogens

Organisms very small to be seen with the naked eye known as also microorganisms or pathogens cause disease in plants, animals, and humans including bacteria (e.g., vibrio cholerae), viruses (e.g. enterovirus, hepatitis A & E virus), fungi (e.g. candida albicans), protozoa (e.g. entamoeba histolytic, giardia lamblia) and helminthes (e.g. Schistosoma mansion, a saris lumbricoides, etc. Microorganisms are excreted in large quantities in the feces of infected animals and humans.

3.1.4 Recycling and Reuse of water

Water is a finite resource that is often taken for granted. Besides urbanization and increasing population impose a great threat to available water supplies. The temporal and spatial distribution of water is also a major difficulty with groundwater resources being overdrawn. It is for these reasons that recycling and reuse are crucial for sustainability [10].

4. Pollutants present in industrial wastewater

The growth of whole biological entities in water is greatly regulated by the physiochemical properties of water [11]. Different Physico-chemical parameters are used for testing water quality such as color, temperature, hardness, pH, turbidity, sulfate, chloride, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), etc. Furthermore, Heavy metals like Pb, Cr, Fe, Hg, etc are of special concern because they produce water or chronic poisoning in aquatic animals.[12].

Table 2 Different Industrial sectors and their major water pollutants

Sectors	**Major water Pollutants**	**References**
Dye manufacturing	Copper, color, salt, sulfides, formaldehyde	[14]
Paint manufacturing	Chromium, zinc, lead, volatile organic compounds (VOCs)	[14]
Textile	Iron, chromium, chlorinated compounds, urea, salts, hydrogen peroxide, high pH NaOH, surfactants	[15]
Pharmaceutical	Cadmium, nickel, phenolic compounds	[14, 16]
Petrochemical	Petroleum hydrocarbons, phenolic compounds, nitrobenzene, alkanes, chloroalkanes, high salt, etc.	[16]
Paper and pulp	Organic and chlorophenols compounds, suspended solids, AOX, lignin, tannins, sterols, colors, biocides, etc.	[17]
Metal working	Perfluorooctane sulfonate (PFOS), ammonium nitrogen, cyanide, phenol, oil, and grease	[18]
Plastic	Perfluorooctanoic acid (PFOA), lead, mercury, cadmium, diethylhexyl phthalate	[18]
Agriculture	Fertilizers, pesticides, insecticides	[19]

A huge quantity of polluted wastewater is released from various industries, which includes the manufacturing of batteries, mining, toxins, and electroplating. These wastewater toxins cause numerous antagonistic impacts on living creatures and the surrounding environment [13]. Contaminant types present in industrial wastewater rely upon the production process. Toxins of industrial wastewater usually include large constituents of organic compounds, increased pH levels, harmful substantial metals, huge saltiness, and increased turbidity from the presence of impurities of inorganic compounds leading to changes in the physical-chemical properties of pure water. Some major industrial sectors and the water pollutants released by them are summarized in Table 2.

5. Methods used for industrial wastewater treatment

5.1 Screening

It is the oldest treatment method that discards solid particles or larger particles from industrial wastewater. It protects downstream equipment from damage, avoids any kind of interference regarding plant operation as well as prevents objectionable floating elements from entering the primary settling tanks. Parallel bars, rods or wires, grating, wire mesh, or perforated plates are used for making screening devices. Several types of screening devices. The retained material is called screenings which are either disposed of by burial or incineration or returned into the waste flow after grinding. Screens of different sizes are applied as per the size of particles i.e coarse screens, fine screens, very fine, and micro screens [20].

5.2 Sedimentation

In the case of wastewater treatment sedimentation is a widely used process allowing the gravitational settling of heavy particles suspended in a mixture. This process is undertaken to remove grit, particulate matter in the primary settling basin, biological floc in the activated sludge settling basin, and chemical flow when the chemical coagulation process is used. Sedimentation occurs in a settling tank, also known as a clarifier [20]. Chemicals can be added to the aqueous media externally to accelerate the process. The efficiency of sedimentation depends largely on the flow rate, time of detention, and solid loading [21].

5.3 Floatation

For discarding solid or liquid particles from a liquid phase by introducing a fine gas, usually air bubbles, and these gas bubbles either adhere to the liquid or are trapped in the particle structure of the suspended solids, raising the buoyant force of the combined particle and gas bubbles and this process is named as Floatation. Mainly floatation is addressed to remove suspended matter and to concentrate biological sludge. Through Floatation very small or light particles can be removed more completely and in a shorter time [20].

5.4 Membrane filtration

Membrane filtration, the process in which a porous or non-porous membrane is present, is used to filter out the metal from the mixed metal wastewater. The material used, the pore size of the membrane, and the composition of the wastewater influence mostly the behavior of the membranes. This technology comprises microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). The MF is somewhat similar to that of UF. Mainly as the pre-treatment process MF works and under low pressure effectively it is circulated. It separates the suspended or colloidal particles present in the wastewater. 10–150 μm is the thickness of the surface film in this case which cast off bacteria, clay, particulates, oil, grease, and organics [22].

Furthermore, the thickness of the surface film is usually 150–250 μm for UF which discards macromolecules, proteins, viruses, and polysaccharides and requires less energy with higher efficiency. NF, pore size 0.001 μm, separate compounds having a low molecular weight efficiently that requires high pressure to pass water. The thickness of the surface film is usually 150 μm which discards high molecular weight compounds, monosaccharides, disaccharides, and oligosaccharides. It also removes heavy metals from the wastewater strongly. By using a semi-permeable membrane salt as well as multivalent ions from the wastewater can be removed by RO process commonly in which the thickness of the surface film is 150 μm. At the same time, this membrane can cast off high and low molecular weight compounds, glucose, proteins, sodium chloride, and amino acids [23].

5.5 Chemical precipitation

In this process, several types of chemicals are introduced to separate metals from the wastewater. Precipitation i.e hydroxide precipitation, sulfide precipitation, and chelating precipitation are occurred under this process depending upon the pH changes. Here, Sludge is generated in the bulk amount which imposes an extra cost for its management and disposal [24]. The effectivity mainly relies on the metal concentration and type of wastewater, conditions of the reaction, and the existence of compounds that can cause reaction inhibition [25].

5.6 Adsorption

It is a conventional method of metal removal from wastewater. In this process, a solid phase known as adsorbent is passed through the wastewater containing metals and then the selective metals get adsorbed on the surface from where they can be collected separately. It is noted that once the metal is collected from the adsorbent, it can be regenerated by the process of desorption. The adsorbent can be extracted from agricultural waste, by-products of industries, and natural substances. Activated carbon is the mostly used adsorbent. Sawdust, rice husk, carbon nanotubes, fly ash, zeolite, water hyacinth, orange peel pith, coconut coir pith, sunflower, etc also act as the adsorbent. The cost of activated carbon varies with the selectivity of adsorbents. Some of the adsorbents have low adsorption capacity, mechanical weakness and sometimes get dissolved in acidic conditions. Which play a vital role in this process. In this process, the selection of adsorbent plays an important role and waste products are generated which again requires more attention [26].

5.7 Ion exchange

Basically, it is the process of interchange of ions between the liquid and the solid phase hanging on various factors like pH, temperature, anions, initial concentration of the adsorbent and sorbate, and the contact time affecting the exchange of ions. Natural or synthetic resins are usually used for the removal of metals from wastewater although existing some disadvantages in it. One is due to the high cost of the utilized resins and their sensitivity to the removed particles; the efficiency of metal extraction is low and another is the necessity to change the resins frequently due to the reused resins' rapid degradation and bad odor [26].

5.8 Coagulation

Small particles are amalgamated into bigger aggregates (flocs) through the process of coagulation, which also assists to adsorb dissolved organic materials onto particulate aggregates for later cleanup during solid/liquid separation [27]. The three key functions of the coagulation-based organic elimination method are as follows: Metal ions and negatively charged organic colloids are electrically neutralized, destabilized, and aggregated in phase 1; positively charged metal ions and negatively charged organic matter molecules form insoluble complexes and precipitates in phase 2, and organics are physically and chemically adsorbed on the surface of alum in phase 3. Conventional coagulation technology has indisputably not met people's need for quality safety as environmental water issues become more serious and water quality standards become tougher. To accomplish the effect of advanced water and wastewater treatment, enhanced coagulation and optimized coagulation are developed based on current water treatment process facilities and by taking into account the operating circumstances of prior and subsequent process flows [28].

5.9 Flocculation

One of the most prominent solid-liquid separation methods for removing colloids, suspended and dissolved materials, and organic materials from industrial effluent are flocculation [29]. It has been extensively employed to address a variety of wastewater types, namely palm oil mill effluent, textile wastewater, pulp mill wastewater, oily wastewater, sanitary landfill leachates, and others. It is a simple and cost-effective approach for treating wastewater [30,31,32,33]. Since inorganic coagulants are inadequate at treating wastewater with small dosages and limited applications, their use has decreased in modern times. Most of the time, polymeric flocculants are preferred to speed up the separation process, coagulant or not. Until now, a variety of flocculants, also known as coagulant aids, including synthetic or natural organic flocculants and grafted flocculants, have been discovered or developed to boost the flocculation process in wastewater treatment. Because of their intrinsic inertness to pH fluctuations, remarkable efficiency with hardly any dosage, and ease of handling, polymeric flocculants—both synthetic and natural—have become increasingly popular in the treatment of industrial effluent [34].

5.10 Advanced oxidation processes

Advanced oxidation processes (AOPs), which generate highly powerful radicals such as hydroxyl and sulfate radicals for the degradation of organic pollutants present in the water medium, are emerging for wastewater treatment. Biodegradability improvement is one core benefit associated with AOPs. Among the various strategies, Fenton oxidation has gained wide attention regarding the remediation of homogeneous and heterogeneous wastewater. Iron salt, zero-valent iron (ZVI), and iron minerals are used either alone or in a composite form. The electrochemical advanced oxidation process (EAOP), which utilizes electricity to enhance the chemical reactions to produce radicals, is also widely accepted compared to the efficiency of Fenton-based treatment techniques with ozone-based treatment techniques for the treatment of homogeneous and heterogeneous industrial wastewater. Fenton process operated with hydrogen peroxide to ferrous ion weight ratio of 6:1 was able to remove more than 95% and 85% COD sequentially from homogeneous and heterogeneous wastewater, respectively. Additionally, the maximum COD removal efficiency of ozonation for homogeneous and heterogeneous industrial wastewater was only 28% and 32%, respectively [35].

5.11 Electrochemical treatments

Electrochemical technologies have proven to be powerful methods for the treatment of numerous kinds of industrial waste. The success of the treatment mainly relies on the physicochemical properties of the wastewater and the electrode materials and thus the type of process that is applied. Particularly EAOPs, based on the production of OH, are highly efficient in degrading dissolved organic pollutants, especially aromatic/cyclic and unsaturated compounds which possess the highest reaction constants with OH. Hence, effluents containing important amounts of such organic contaminants are excellent candidates for EAOP treatment, including pharmaceutical, food processing, textile, reverse osmosis (RO) concentrates, and landfill leachate effluents, as well as other waste streams from various chemical sectors. Highly loaded effluents are also ideal candidates for OH-based EAOPs because high concentrations of organics avoid mass transport limitations that are generally associated with electrochemical methods. Nevertheless, very high contents of organic matter require longer treatment times and extensive energy consumption, hurting the feasibility of the treatment [36].

5.12 Electrocoagulation process

Presently Electrocoagulation process receives great attention due to its COD, color removal efficiencies, cost-effectiveness, less sludge generation, and environmental compatibility. It is a separation technique in which both physical and chemical mechanisms for pollutant removal are involved whereas mainly the suspended, dissolved, or emulsified pollutants are destabilized in the aqueous medium by supplying the electricity. It may be a potential answer to environmental problems by successfully dealing with water reuse, recycling, and sludge management. When the effluents from various industries are considered by taking into account the technical and economic factors involved, EC claims to offer efficient removal rates for almost all types of wastewater at a low cost [37].

5.13 Novel biofiltration methods

In general, heavy metals are well-known toxic and carcinogenic agents and when discharged into the wastewater exhibit a serious threat to the human population and living organisms as well as the receiving water bodies. There is a high chance for the effective application of biofilters for the removal of toxic heavy metals from contaminated water on a large scale. The success of the microbial cloning technique may improve the removal efficiency and hence the reduction in treatment cost. Since it is capable of removing heavy metals up to ppb level and is cheaper, application of this technique for the treatment of wastewater of the industries like chemicals and fertilizers, textiles, pulp and paper, dyes and pigments, pharmaceuticals, etc. will help these units to meet the statutory mandate and to alleviate the threat for survival due to high wastewater treatment cost of these units. In short, biofilters are having emerging applications for the treatment of heavy metals contaminated wastewater [38].

5.14 Biodegradation

In the case of mixed industrial wastewater treatment based on the bacterial population used, biological processes are performed in reactors operated in aerobic mode including activated sludge, trickling filter, MBR, lagoons, and oxidation ditches, and anaerobic mode including internal circulation (IC) reactor, anaerobic baffled reactor, expanded granular sludge bed reactor, fluidized bed reactor, upflow anaerobic sludge blanket (UASB) reactor, anaerobic filter, and anaerobic contact process. The anaerobic biological process combined with an aerobic process has been used to treat industrial wastewater where high-quality water is generated, which can be reused in the industry itself. UASB or MBRs, where membrane separation is combined with the activated sludge process is prominent in this case. The operation of full-scale UASB followed by the use of a ceramic membrane bioreactor to treat industrial wastewater containing grease, oil, and inorganic materials also get big acceptance. The effluent treatment by microbes followed by activated charcoal detoxification is also emphasized by researchers in which the bacteria i.e. Escherichia Ferguson, isolated from domestic wastewater, reduced COD, color, TDS, sulfates, chlorides, calcium, and bicarbonates by 81%, 98.4%, 75%, 87%, 64%, 84%, and 83%. Further reduction in COD was observed after detoxification with activated charcoal. Moreover, Cyanobacteria, called blue-green algae, has gained recent attention in pollutant reduction levels because of their photoautotrophic nature along with their ability to fix atmospheric nitrogen makes them good producers and reduces the cost of growth and maintenance of these microbes. Inhabitancy and survival of cyanobacteria in the polluted aquatic environment have evoked researchers to utilize it to treat industrial WW, especially three different cyanobacterial species, including Tolypothrix ceytonica, Anabaena variabilis, and Anabaena oryzae, were used to assess the potential of CETP wastewater treatment [35].

5.15 Biosorption

It is one of the most prominent strategies to remove metals from a contaminated environment in which either live or dead microbial cells and microbial metabolic products such as polymers are utilized for binding of metals occurs by either physisorption involving Van der Waals attractions or chemisorption involving chelation, precipitation, ion exchange processes, and metal complexation by cell components. Various marine bacteria, siderophore producers, have shown promising results in eliminating metals from wastewater including iron, magnesium, manganese, and chromium. It is revealed that M. hydrocarbonoclasticus was identified as the most effective to eliminate chromium from wastewater under both aerobic and anaerobic conditions. The most economical means of detoxifying Cr (VI) is to reduce it to Cr (III) via microbial adsorption and reduction. In addition, A cyanobacterial species, Tolypothrix claytonia has shown promising results in adsorbing heavy metals from mixed domestic industrial wastewater [35].

5.16 Combination of Anaerobic & Biofiltration process

A treatment process combining the action of anaerobic and biofiltration is used in recent times whereas the anaerobic process followed by Up-flow Anaerobic Sludge Blanket (UASB) process and Bio-filtration was maintained by polyurethane materials followed by a down-flow process to remove pollutants from industrial wastewater, especially in textile industries. The treatment process is effectively generated without any chemical treatment process. Moreover, this advanced high-rate biological process is hazard-free, highly effective, has a low operational cost, has high-rate treatment capacity, is a simple process, has low electricity use, and is also an economically viable process than the Chemical ETP process [39].

5.17 Efficacy of microalgae to treat wastewater

Biotransformation of pollutants using microalgae has proven to be a proficient and economic method of wastewater treatment because of their adaptability to growing in industrial wastewater flows and is also useful in the process of CO2 fixation. The algal treatment has been proven to be an effective as well as an efficient, eco-friendly method as the conventional method of treatment of industrial effluent requires more investment and operating cost. Additionally, the microalgae can discard more than 90 % of nutrients and some extent of toxic chemicals and heavy metals from the industrial effluent and it can be further increased by using growth stimulators or by developing growth. It must be noted that microalgae not only have the potential to treat industrial wastewater but are also used to produce biomass energy and biofuel [40].

5.18 Microbial biofilm reactor

It is not economical wise to treat high-strength industrial wastewater through the suspended growth activated sludge process due to its high aeration energy requirement. In this case, Biofilm-based treatment options provide a suitable alternative for the treatment of concentrated waste streams generated from different industries. Over the last few decades, several biofilm-based wastewater treatment technologies were established whereas Biofilm reactors retain microbial cells in the form of biofilm which is attached to free-moving or fixed-carrying materials, thus providing a high active biomass concentration and automatic liquid and solid separation. Nowadays, microbial biofilm reactors have been widely used in high-strength wastewater treatment where very high pollutant removal efficiency is required because it's not only removing carbon, nitrogen, and sulfur but also a variety of oxidized contaminants including perchlorate and bromate [41].

5.19 The combined action of electrochemical advanced oxidation and biological processes

As the inlet characteristics of the wastewater differ as per the industry and its processes, the treatment of mixed industrial wastewater has gained more attention presently. Through a combination of electrochemical advanced oxidation processes (EAOPs) and biological treatment, this problem can be solved greatly which Electro Fenton process is considered to be an important EAOP because of its short reaction time along with external persulphate addition was applied before the biological treatment. Advanced Oxidation Processes (AOPs) thereby seek more attention as it is an efficient process to remove such toxic recalcitrant and non-biodegradable matters present in the wastewater In the last decade, the EAOPs have played a vital role in the treatment of wastewater as it tends to eliminate various organic pollutants from the wastewater. Here, firstly the non-biodegradable organic compounds get converted into biodegradable products, and finally, with the help of biological treatment, the products are removed [42].

Table 3 Advantages & disadvantages of various methods

Process	**Advantages**	**Disadvantages**	**References**
Biological	Cost-competitive option. Direct, dispersed, and basic dyes have a high level of adsorption onto activated sludge.	Dyes are generally toxic and very resistant to biodegradation. Acid and reactive dyes are highly water soluble and have poor adsorption onto sludge	[43]
Coagulation	Economically feasible; satisfactory removal of dispersing, sulfur, and vat dyes	Removal is pH-dependent; produces a large quantity of sludge. May not remove highly soluble dyes; unsatisfactory result with azo, reactive, acid, and basic dyes	[44, 45]
Activated Carbon adsorption	Good removal of a wide variety of dyes, namely, azo, reactive, and acid dyes; especially suitable for basic dye	Removal is pH dependent; unsatisfactory result for disperse, sulfur, and vat dyes. Regeneration is expensive and involves adsorbent loss; necessitates costly disposal.	[46]
Ion exchange	The adsorbent can be regenerated without loss, and dye recovery is conceptually possible	Recovery is conceptually possible. Ion exchange resins are dye-specific; regeneration is expensive; large-scale dye recovery is cost-prohibitive.	[47]
Chemical oxidation	Initiates and accelerates azo-bond cleavage.	Thermodynamic and kinetic limitations along with secondary pollution are associated with different oxidants. Not applicable to dispersed dyes. Negligible mineralization is possible, and the release of aromatic amines and additional contamination with chlorine (in the case of NaOCl) is suspected.	[48]
Advanced oxidation process	Generate a large number of highly reactive free radicals and by far surpass the conventional oxidants in decolorization	AOPs in general may produce further undesirable toxic byproducts and complete mineralization may not be possible. The presences of radical scavengers reduce the efficiency of the processes some of which are pH-dependent. Cost-prohibitive at their present stage of development	[48]
UV/O_3	Applied in the gaseous state, no alteration of volume. Good removal of almost all types of dyes; especially suitable for reactive dyes. Involves no sludge formation, necessitates short reaction times	Removal is pH dependent (neutral to slightly alkaline); poor removal of dispersed dyes. Problematic handling, impose additional loading of water with ozone. Negligible or no COD removal. High cost of generation coupled with a very short half-life and gas-liquid mass Transfer limitation.	[49]
UV/H_2O_2	Involves no sludge formation, necessitates short reaction times and COD reduction may be possible to some extent	Not applicable for all dye types, requires separation of suspended solids, and suffers from UV light penetration limitation. Lower pH is required to nullify the effect of radical scavengers	[50]

Fenton's reagent	Effective decolorization of both soluble and insoluble dyes; applicable even with high suspended solid concentration. Simple equipment and easy implementation. Reduction of COD (except with reactive dyes) is possible	Effective within a narrow pH range of <3.5; and involves sludge generation. Comparatively longer reaction time require.	[51]
Photocatalysis	No sludge production, considerable reduction of COD, and the potential of solar light utilization.	Light penetration limitation, fouling of catalysts, and the problem of fine catalyst separation from the treated liquid (slurry reactors)	[52]
Electrochemical	Effective decolorization of soluble/insoluble dyes; reduction of COD possible. Not affected by the presence of salt in wastewater.	Sludge production and secondary pollution (from chlorinated organics, and heavy metals) are associated with electrocoagulation and indirect oxidation, respectively. Direct anodic oxidation requires further development for industrial acceptance. The high cost of electricity is an impediment. Efficiency depends on the dye nature	[53]

6. The scenario of industrial wastewater management in Bangladesh

In Bangladesh, the urban area is mostly polluted by industrial pollutants through surface water pollution. An industrial survey regulated by Bangladesh Center for Advanced Studies in 2009 revealed that only 40% of industries had ETPs. At that time 10% of industries were under construction and about 50% of industries have no ETP establishment. Regarding overall emission (especially BOD, TSS) into the water, the pulp and paper industry is the major contributor (47%) in this case, respectively for pharmaceuticals (16%), metal (14%), food industries (12%,), fertilizer/ pesticides (7%), industrial chemical (1%), and other industries (3%) including the cumulative contribution of cement and clay, textile, wood and furniture, tanneries and leather and petroleum industries. The worst affected by unplanned industrialization are Dhaka and its surrounding area including Gazipur, and Narayanganj which exhibit severe water pollution. Moreover, some peripheral rivers border Dhaka city and the water of these rivers is too contaminated to use as potable water. In addition, a total of 19 primary and 41 secondary discharge points exist in the rivers in this whole city. Even the nearest areas of these rivers are also affected by untreated wastewater discharged from various industries which deteriorates the water quality. Every single day peripheral rivers of Dhaka accepted 1.5 million cubic meters of wastewater extracted from 7000 industrial units in the surrounding area and another 0.5 million cubic meters from other sources reported by the World Bank. Tanneries located in Hazaribagh and Rayer Bazar in Dhaka city were liable for disseminating 15,000 cubic meters of liquid wastes, 19,000 kilograms of solid wastes, and 17,600 kilograms of BOD into the Buriganga river per day before repositioning to Savar Upazila. Furthermore, in the last 20 years, an unplanned industrial cluster has been developed at kaliakoir Upazila under Gazipur district only 25 km northeast of the capital dispersing 30 billion liters of effluent into the closest water bodies i.e. Mokosh Beel, Turag river, Ratanpur Khal. A large number of effluents and solid wastes are discharged into different water bodies released from large numbers of textile dyeing industries along with other industries situated surrounding the D.N.D embankment and in the end, pollutants enter into Shitalakshya river. Any kind of treatment plant is absent for around 80% of the total industries and consequently untreated toxic effluent emits into those surrounding water estuaries. Similarly, in the Chittagong district, the Karnaphuli River is exposed to severe water pollution whereas untreated effluents come from different industries such as spinning mills, dying, cotton, textile, steel mills, oil refineries, and other industries. In the coastal region of Bangladesh, the Ship breaking industry is considered one of the fastest-growing industries in Bangladesh which is a vital contributor to trace metal pollution in seawater and groundwater. According to the department of public health and Engineering of Bangladesh only filtration, coagulation, flocculation, ion exchange, adsorption, and chlorination processes are included in the ETP process which is very minimal to treating industrial wastewater effectively [5].

7. Conclusion

The public demand for pollutant-free waste discharge to receiving waters has made decontamination of industrial wastewater a top priority. However, this is a challenging task. It is also difficult to define a universal method that could be used for the elimination of all pollutants from industrial wastewater. This review paper presents several methods of industrial wastewater treatment along with the pros and cons of some. So that it is helpful to choose hazard-free, highly effective, low operational cost, high-rate treatment capacity, simple process, low electricity use, and also economically viable process which is vital for developing countries like Bangladesh.

Compliance with ethical standards

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All authors state that there is no conflict of interest.

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