ORIGINS, EFFECTS AND TREATMENT OF WASTEWATER: UNVEILING THE SOURCES AND SOLUTIONS

Abstract

In a world thirsting for solutions, this chapter embarks on an enlightening journey through the complex domain of wastewater treatment—a voyage transcending the realms of science, engineering, and our shared responsibility as caretakers of the environment. It commences by revealing the various types of wastewaters and their sources, peeling back the layers of factors contributing to their spread, spanning from everyday household activities to industrial and agricultural processes. Within this captivating tapestry of water-related challenges, the chapter unfolds a thorough analysis of associated risks and pollutants, highlighting the impending dangers to ecosystems and human well-being. Digging deeper, it explores the physical and chemical aspects of wastewater, shedding light on key parameters like Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), crucial measures for evaluating wastewater quality. The microbial aspect provides further insight into the intricate communities inhabiting these aquatic environments. The chapter emphasizes the complex relationship between wastewater composition and its profound impact on public health, elucidating the multifaceted ways improper wastewater management can affect communities and individuals, emphasizing the urgent need for effective treatment solutions. The final section skillfully guides readers through a range of wastewater treatment systems, encompassing both traditional methods and cutting-edge technologies, providing them with the necessary knowledge to make

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informed decisions in the pursuit of sustainable wastewater management. This chapter serves as a comprehensive compendium, offering a panoramic view of the intricate challenges and innovative solutions in the vital realm of wastewater treatment.

Keywords: Wastewater, Contaminants, Physio-chemical attributes, Wastewater Treatment Plants.

I. INTRODUCTION

Renowned anthropologist and natural science writer Loren Eiseley once eloquently stated, "If there is magic on this planet, it is contained in water" [1]. Throughout the years, this sentiment has resonated with us more profoundly than ever. Presently, Earth stands as the solitary known celestial body harboring the vital element of life, Water. Recent confirmations by NASA have identified that sporadic water flows on another celestial neighbor, Mars, albeit in minuscule quantities [2]. Beyond its mere existence, the extent of water's prevalence on our planet is indeed remarkable. Geographical analysis reveals that approximately 333 million cubic miles of Earth's surface is enveloped by this life-sustaining resource. However, the staggering figure is tempered by the fact that only 2.5% of this colossal water reservoir is categorized as fresh, with the remaining vast majority residing in saline bodies or oceans [3].

Of this 2.5%, a mere 1% is accessible for human utilization, as the remainder exists in the form of frozen glaciers and snowfields. Consequently, when juxtaposing the finite water resources against the burgeoning global population, a stark reality emerges: a mere 0.007% of Earth's water is available to cater to the needs of the 6.8 billion individuals inhabiting our planet [3].

It is imperative to acknowledge that water assumes a pivotal role in sustaining human life, underpinning essential facets such as drinking, agriculture, industry, commerce, energy production, recreation, and more. This realization underscores the pressing need for responsible and sustainable water management in a world where this precious resource remains both scarce and indispensable.

The escalating global population is poised to exert increased demands on our water resources, potentially jeopardizing their sustainability. However, a notable observation reveals that water consumption has outpaced population growth, doubling in rate over the course of the past century. Furthermore, our already limited water reserves face additional stressors from natural calamities such as climate change, shifting weather patterns, and alterations in global waterfall patterns. These phenomena culminate in localized flooding and drought conditions, compounding the issue [4].

Notably, this water scarcity predicament is further exacerbated by anthropogenic activities, including rapid urbanization, escalating pollution levels, inadequate resource management, and various other human-driven factors. The collective impact of these actions leads to a deteriorating quality of life, perpetuating a concerning cycle of water scarcity [4].

The advancement of artificial intelligence (AI), especially in the training of large language models, heavily relies on substantial computational power, a process that generates considerable heat. To efficiently dissipate this heat and maintain optimal operating conditions, data centers require significant volumes of water for cooling purposes. Recent disclosures by Microsoft indicate a noteworthy increase of 34% in its global water usage between 2021 and 2022, primarily attributed to its AI research initiatives, including its collaboration with OpenAI [5].

An upcoming research paper, led by Shaolei Ren at the University of California, Riverside, offers valuable insights into the water consumption associated with AI models like ChatGPT. According to the study's projections, each interaction with ChatGPT is approximated to utilize around 500 milliliters of water. This estimation encompasses not only direct water consumption but also the indirect use of water linked to the coolingprocesses of power plants that supply electricity to data centers. These findings shed light on the environmental ramifications of AI development and emphasize the significance of adopting sustainable practices within this rapidly evolving field [5].

In light of this analysis, it is anticipated that by 2025, approximately 1.8 billion individuals will grapplewith water scarcity, while roughly two-thirds of the global population will confront water stress. Another pivotalcontributor to this scarcity is the escalating volume of wastewater originating from our existing water sources [6]. Thus, all these impacts have collectively led us to believe that Loren Eiseley's "Magical Water" is now becoming a wicked problem. This is in context of the fact that as we make an attempt to solve one issue pertainingto water scarcity or purity, we are faced with another one. This thus suggests the dire need for accurately evaluating the current status of wastewater and appropriate measures to resolve the same.

Wastewater, a term subject to various expert definitions depending on specific criteria and intended uses,can be concisely described as water that has undergone physical, chemical, or biological alterations rendering it unsuitable for consumption [7]. Additionally, it is characterized as water contaminated by residential, agricultural, or commercial activities, comprising approximately 99.9% water and 0.1% impurities, encompassing organic matter, inorganic compounds, or microorganisms [8].

In light of the comprehensive descriptions provided thus far, the most widely accepted and descriptive characterization of wastewater encompasses water containing a notable concentration of solids, typically within the range of 350 - 1200 mg/L. It further comprises dissolved and particulate matter, the quantification of which isdetermined by the chemical oxygen demand (COD) levels, typically ranging between 250 - 1000 mg/L. Additionally, wastewater can harbour heavy metals, nutrients, and micropollutants, the presence of which is contingent upon the source of the wastewater [9]. It is imperative to underscore that wastewater is unsuitable for primary use, thereby compounding the issue of water scarcity. Therefore, before delving further into this discourse, it is crucial to provide an elucidation of the contaminants prevalent in wastewater.

II. POLLUTANTS IN WASTEWATER

The first section of this chapter describes the type of pollutants present in wastewater, the sources from which these pollutants are generated and the consequences that these pollutants have on human health, animal diversity especially aquatic diversity and on the environment as a whole.

1. **Organic Pollutants:** This category encompasses carbon-based chemicals, including but not limited to organic solvents, dyes, humic liquids, phenolic compounds, gasoline, surfactants, pesticides, and pharmaceuticals. Recent studies highlight the diverse effects of these contaminants, primarily originating from industrial domains such as textiles,

automobiles, pharmaceuticals, and pesticide production. The identified outcomes encompass the deterioration of water quality and disturbances in aquatic ecosystems, which have been extensively seen to impact the growth and reproductive behaviours of aquatic species. Notably, pharmaceutical residues have been found to induce endocrine disruption in fish. In addition, research indicates that these contaminants may undergo chemical changes in water, producing undesirable byproducts that may be even more hazardous than the original parts. Certain types of organic pollutants, such as pharmaceuticals and persistent organic pollutants (POPs), have been observed to exhibit bioaccumulation in aquatic creatures, hence leading to bio-magnification within the food chain. The presence of drugs and antibiotic-resistant genes in wastewater, caused by pharmaceutical pollution, gives rise to significant public health concerns related to antibiotic resistance. The various characteristics of organic pollutants present considerable obstacles to standard wastewater treatment processes. Certain compounds necessitate the use of advanced treatment techniques, such as advanced oxidation and membrane filtration, in order to achieve thorough removal of contaminants. Recent research has played a crucial role in illuminating the intricacies surrounding this subject matter, so permitting an improved understanding of the environmental and health hazards linked to organic pollutants present in wastewater. Furthermore, these studies have been helpful in propelling the advancement of techniques aimed at mitigating the adverse effects caused by these pollutants. While several methods exist for mitigating these pollutants, such as direct ozonation, UV photolysis, high voltage electrical discharges, heterogeneous photo-catalysis, cavitation, electrochemical oxidation, Fenton processes, Photo-Fenton processes, bioremediation, and phytoremediation, it is noteworthy that these disinfection processes can yield a spectrum of toxic chemicals hazardous to human health [10].

2. **Pathogens:** Wastewaters host an array of microorganisms, categorized as both pathogenic and non-pathogenic. Non- pathogenic strains include *Chromobacterium violaceum* and certain *E. coli* variants, which, while not directly posing health risks, can indirectly influence water quality. Conversely, pathogenic microbes encompass bacteria, viruses, parasitic protozoans, and helminths [11]. These pathogens infiltrate wastewater through diverse sources, including human and animal faeces, with fecally contaminated water from activities like bathing and washing being significant contributors to the introduction of enteric pathogens [12].

   Among the most prevalent bacterial pathogens in wastewater are *Salmonella spp., Escherichia spp., Shigella spp., Yersinia spp., Klebsiella spp., Leptospira spp., Vibrio cholerae, Aeromonas hydrophila, Legionella pneumophila, Mycobacterium spp., and Pseudomonas spp.* [11,13,14]. Furthermore, viruses, including enteric viruses like *hepatitis A, norovirus, rotavirus, adenoviruses, astroviruses*, and various enteroviruses, are prevalent in wastewater (*Ashbolt, 2004, Cai and Zang, 2013*). Recent studies have detected novel viruses like the *Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV-2)*, which has been responsible for the global pandemic [15]. Zoonotic viruses, such as animal *adenoviruses, sopaviruses, and Hepatitis E*, have also been introduced into wastewater through industrial waste [16]. Additionally, pathogenic plant viruses like *pepper mild mottle virus* and *tobacco mosaic viruses* have been identified in human faeces and wastewater [17].

Protozoans, larger than bacteria by up to tenfold, constitute another significant group within wastewater microorganisms. Common parasitic protozoa found in sewage include *Cryptosporidium parvum*, *Cryptosporidium hominis*, and *Giardia duodenalis*, originating from faecal matter of infected humans or animals[18].

3. **Nutrients:** Among the frequently encountered constituents in wastewater, phosphorus and nitrogen stand out as the most prevalent nutrients. These elements assume paramount importance as they serve as vital nutrients for the growth and proliferation of aquatic plants and algae. In addition to their fundamental roles, nitrogen exists in various forms—ammonia, nitrite, or nitrate—and is utilized by a diverse spectrum of bacteria, including *Nitrosomonas spp., Nitrosococcus spp., Nitrosospira spp., Nitrosolobus spp., Nitroso vibrio spp., Nitrobacter spp., and Nitrospina spp* [19].

Excessive concentrations of nitrates in particular have substantial environmental repercussions. This surplus can induce adverse effects on water quality and marine ecosystems, exemplified by conditions like "blue- baby syndrome" or methemoglobinemia, which entail a significant drop in blood oxygen levels, occasionally resulting in fatal outcomes. Elevated levels of nitrogen and phosphorus can also trigger the proliferation of algae and other nuisance aquatic vegetation in water bodies, a phenomenon known as eutrophication. This phenomenon can lead to foul odours and a reduction in dissolved oxygen levels, a condition referred to as hypoxia, stemming from the decay of algal blooms. Such hypoxic conditions, as observed in regions like the Gulf of Mexico, pose threats to economically and ecologically valuable fish and shellfish populations [20].

Remarkably, as per data submitted to the United States Environmental Protection Agency in 2004, a staggering 51% of examined water bodies were deemed too polluted for basic activities like fishing and swimming, owing to their nutrient content. The primary culprits responsible for elevated levels of phosphorus and nitrates in wastewater are agricultural fertilizers. These nutrients feature prominently in both synthetic and natural fertilizers, including manure. Surplus fertilizers that remain unabsorbed by crops are prone to runoff, carried into waterways by rainfall or stormwater. Subsequently, stormwater is channeled into urban drainage systems before ultimately discharging into streams and rivers enriched with phosphorus and nitrogen [21].

In addition to agricultural sources, the combustion of fossil fuels introduces nitrogen oxides and ammonia into the atmosphere. When these compounds settle into aquatic environments, they can significantly contribute to the overarching nutrient issue. Various methods have been devised to address the conversion of reactive nitrogen and ammonium. These encompass nitrogen fixation, ammonification, denitrification, and Annamox. Furthermore, coagulation and filtration techniques employing iron salts find widespread application in reducing phosphate levels in both drinking water and wastewater.

The Environmental Protection Agency (EPA) played a pivotal role in establishing phosphorus recommendation requirements, with specifications instituted in 1986. These stipulations include limits of 0.1 mg/L for streams that do not discharge into reservoirs, 0.05 mg/L for streams that do, and 0.024 mg/L for reservoirs [21]. It is worth noting that

the Bureau of Indian Standards (BIS) does not prescribe a permissible limit for phosphate in drinking water. However, the World Health Organization (WHO) took the initiative in 1993 to set a standard of 0.1 mg/L [22].

Moreover, regulations governing nitrate and nitrite levels in drinking water quality are well-defined. In the United States, the National Primary Drinking Water Regulations establish maximum contaminant levels of 10 mg/L (10 ppm) for nitrate and nitrite, or 1 mg/L (1 ppm) for nitrite specifically [23]. Meanwhile, European Union national drinking water quality standards set nitrate and nitrite limits at 50 mg/L (50 ppm) and 0.5 mg/L (0.5 ppm), respectively [24].

4. **Suspended Solids and Sediments (Organic and Inorganic):** Suspended solids are commonly found in wastewater, often accumulating due to natural processes. Algae primarily contribute to the organic fraction of suspended solids, while inorganic substances like sand and silt alsoplay a significant role. Algal blooms, typically attributed to organic waste, are exacerbated by factors like the presence of excessive nutrients such as nitrogen and phosphorus, often originating from crop runoff or decomposition. Environmental shifts, including higher temperatures and extended daylight hours, can indirectly contribute to these blooms.

Algal blooms have detrimental consequences for water bodies, generating toxins like Domoic acid (produced by *Pseudo-nitzschia*), microcystins, hepatotoxins, and reducing oxygen levels by blocking sunlight, thereby impacting aquatic life [25]. Sediments, on the other hand, encompass solid particles transported by wind, water, or ice that can settle at the water body's bottom. These particles vary in size and composition, including clay with a diameter less than 0.00195 mm, silt ranging from 0.0049 to 0.047 mm in diameter, and coarse sand with a diameter of up to 1.5 mm [26]. Sediments are influenced by water movement and local activities, impacting their volume and distribution.

5. **Inorganic Pollutants (Salts and Metals):** Wastewater, often laden with heavy metals and salts, poses substantial risks to both human health and the environment. These contaminants, frequently originating from industrial effluents and domestic sewage, can have far-reaching consequences. While trace amounts of essential heavy metals like zinc, iron, copper, lead, nickel, and magnesium are vital for metabolic processes, their excessive presence beyond established concentration limits (Maximum Contaminant Levels) can result in severe health ailments when ingested [27]. Nonessential heavy metals, such as mercury, nickel, cadmium, and arsenic, present a grave threat to the human body, leading to irreversible damage including brain impairment, circulatory system disorders, and nervous system dysfunction [28]. Furthermore, heavy metals have the capacity to induce mutagenesis, carcinogenesis, and hereditary genetic disorders through their destabilizing effects on biological structures and molecules [29]. However, it is imperative to address the growing concern of heavy metal resistance observed among bacterial isolates originating from industrial wastewater.

6. **Other Types of Water Pollution:** Water pollution extends beyond particulate matter, encompassing thermal pollution and radioactive pollution as significant contributors to environmental degradation. Thermal pollution arises from temperature fluctuations in

aquatic ecosystems, resulting from processes like industrial cooling and the introduction of cold water, causing harm to aquatic life [30]. On the other hand, the presence of radioactive elements in the Earth's crust, sourced from soil radionuclides and human activities such as nuclear power facilities and weapons testing, leads to contamination of surface and drinking water sources, necessitating stringent monitoring and mitigation efforts [31].

III. FORMS OF WASTEWATER: UNDERSTANDING SOURCES, RISKS, AND CONTAMINANTS

Wastewater generation stems from various sources, encompassing three primary categories known as forms of wastewater: domestic wastewater, industrial wastewater, and stormwater runoff. A comprehensive understanding of these forms is vital for effective wastewater management and mitigating associated risks.

1. **Domestic Wastewater:** Domestic wastewater originates from household and municipal activities, presenting two distinct categories: blackwater and greywater. Blackwater primarily comprises urine and faeces and is considered more hazardous due to its high faecal coliform content. Human waste, or faecal matter, is deemed a biohazard, especially when individuals are unwell, as it may harbour bacteria and pathogens that pose risks if mishandled [32].

   Exposure to blackwater carries numerous consequences, including the potential spread of diseases such as *E. coli* and campylobacteriosis, both of which can lead to severe digestive issues. Bacteria in blackwater release endotoxins into the air, which can result in long-term respiratory diseases upon exposure [33]. Importantly, it is a misconception that blackwater-related problems can be resolved independently. Proper training, protective equipment, and cleaning agents are essential when addressing blackwater to avoid debilitating, long-term illnesses. Long-term exposure can lead to infections, diseases, and chronic respiratory problems, with severe health risks and, in some cases, fatalities associated with encountering it [34].

2. **Greywater:** Greywater predominantly contains easily digestible organisms, nutrients like nitrates and phosphorus, xenobiotic organic compounds, and limited quantities of viruses or bacteria, often originating from kitchen, laundry, or bathroom waste. Additionally, greywater may contain therapeutic drugs, health and beauty products, aerosols, and potentially toxic heavy metals [35].

   Recent microbial monitoring programs, such as one conducted in Melbourne, Australia, have identified the presence of *Escherichia coli* and enteric viruses in greywater, with a significant portion originating from washing sources. The study reported the detection of enteric viruses in 18% of samples, enterovirus in 7%, and *E. coli* in 11% of the samples. Coliforms and *E. coli* are commonly employed indicators to assess contamination levels [36].

   Other studies, conducted by *Eriksson et al. (2002)* [37] and Ottoson and *Stenstrom (2003)* [38], have also identified sewage-related bacteria in greywater. Notably, the presence of pathogens like *Pseudomonas* has been reported in various greywater studies.

3. **Industrial Wastewater:** The generation of industrial wastewater, originating from diverse sectors like healthcare, textiles, agriculture, and pharmaceuticals, presents significant challenges due to its potential for housing pathogenic microorganisms and hazardous chemicals. Recent research highlights the pressing issues associated with this type of wastewater. Industrial wastewater from healthcare facilities and pharmaceutical companies is a notable concern due to the presence of pathogens and harmful chemicals. Research findings indicate the existence of harmful microorganisms, such as *Shigella* and *Salmonella* species, inside these wastewater streams. Furthermore, these effluents contain a variety of microorganisms, including bacteria, yeasts, and filamentous fungi like *Penicillium* and *Aspergillus*. Of particular concern is the discharge of pharmaceutical compounds and the emergence of antibiotic-resistant microorganisms from these sources. *Methicillin-resistant Staphylococcus aureus* (MRSA), *vancomycin-resistant Enterococcus species*, fluoroquinolone-resistant bacteria, and other antibiotic-resistant pathogens are posing significant public health challenges. These resistance mechanisms are mediated by genetic elements like gene cassettes, integrons, plasmids, and heavy metal-resistant genes, facilitating their persistence and dissemination. AMR or antimicrobial resistance has now become one of the most pressing challenges for the researchers around the world and demands immediate attention. Robust monitoring and management strategies are essential to address these issues effectively [39]. In line with the same, WHO has focused on the identification of resistant pathogens across the globe. With the release of Global Priority Pathogen List by WHO in 2017 considering the emerging resistance, a 5-year National Action Plan was prepared from 2017-2022 by WHA (World Health Assembly) in Geneva, for the surveillance of spreading antimicrobial resistance (AMR), antimicrobial use (ARU) as well as antimicrobial consumption (ARC). However, to combat this issue in the field is a long way ahead.

4. **Urban Storm Water Runoff:** Storm water runoff, characterized by the flow of precipitation over surfaces rather than infiltration into the ground, is a prevalent issue, especially in urban areas. Urban environments, featuring impermeable surfaces such as roads and buildings, experience elevated runoff compared to natural landscapes. This phenomenon has several repercussions described below:

  ➢ Increased urban runoff can lead to localized flooding, straining drainage systems and endangering public safety.
  ➢ Storm water runoff accumulates pollutants like oils, heavy metals, and sediments from various surfaces, degrading water quality in nearby water bodies.
  ➢ Urban runoff can transport contaminants, including pathogens, nutrients, and chemicals, from streets and built environments into natural ecosystems, adversely affecting aquatic life and overall ecosystem health.

  Managing storm water runoff in urban settings requires comprehensive strategies, including sustainable urban planning, green infrastructure, and pollution control measures. These approaches aim to mitigate the adverse impacts of runoff on both human communities and the environment [40].

IV. PARAMETERS AND TECHNIQUES FOR WASTEWATER CHARACTERIZATIONS

Characterization of various properties of the wastewater helps in monitoring the quality and efficiency by which it is treated in the wastewater treatment facilities. In addition to providing how well different treatment systems work in different wastewater compositions these parameters also help in determining the applicability or reusability of the treated wastewater in the general public e.g., for irrigation, washing purposes, etc.

1. **Physico-Chemical Characteristics**

- **pH:** The abundance of hydrogen ions in both normal and wastewaters is an effective quality indicator. This parameter is used to define whether wastewater is acidic or basic. Septic states are indicated by a pH of less than 7, whereas pH values of less than 5 and greater than 10 signify the existence of Industrial wastes and incompatibility with biological operations. The pH concentration range required for biological life to survive is very limited (typically 6-9).

- **Temperature:** The temperature of the water is a physical property that expresses how hot or cold it is. It may also be described as a measurement of a substance's average thermal energy. Thermal energy is the kinetic energy of atoms and molecules, and temperature is the average kinetic energy of atoms and molecules. The flow of heat can transfer this energy between substances. Water temperature may be changed by heat transfer from the air, sunlight, another water source, or thermal pollution. Certain physico-chemical qualities of wastewater are affected by changes in water temperature. High water temperatures can increase the solubility and thus toxicity of certain chemicals, in addition to their effects on aquatic species. Heavy metals like cadmium, zinc, and lead, as well as compounds like ammonia, are among these elements. As the temperature rises, the solubility of oxygen and other gases decreases. This means that lakes and streams that are cooler will contain more dissolved oxygen than those that are warmer. Water that is too warm would not be able to carry enough oxygen for aquatic speciesto survive [30].

- **Conductivity, Salinity, and Total Dissolved Solids:** Salinity refers to the amount of salt in a body of water, which may come in a variety of ways. The concentration of salt in water can be determined using one of two methods i.e., Total Dissolved Solids (TDS) and Electrical Conductivity (EC). TDS are determined by drying the water and measuring the solid residue. EC is determined by passing an electric current through water and determining how easily it flows.

- TDS is measured in parts per million (ppm) or milligrams per litre (mg/L) (ppm). MicroSiemens per cm (S/cm) is the normal EC unit. It's commonly referred to as an 'EC Unit'. Among which TDS analysis is commonly thought to be a more precise salinity measurement. The palatability of water with a total dissolved solids (TDS) level of less than about 600 mg/L is usually considered to be good; drinking water becomes drastically and gradually unpalatable at TDS levels greater than about 1000 mg/L, according to the World Health Organization [41]. TDS is not of health concern

at levels found in drinking water, so there is no health-based threshold. Changes in conductivity, salinity, and TDS may affect aquatic life and water quality, regardless of whether they are caused by manmade or natural causes. The majority of aquatic species have developed adaptations to specific salinity levels. Because of changes in dissolved oxygen concentrations, osmosis control, and TDS toxicity, salinity values outside of a normal range can cause fish death [41]. Conductivity and salinity levels that deviate too far from their normal range can be harmful to marine organisms in a body of water. This is why a smaller number of species have adapted to life in estuaries, where salinity is constantly changing. However, if salinity changes become too drastic, even these brackish-water organisms can suffer [42].

- **Dissolved Oxygen (DO):** The amount of free, non-compound oxygen found in water or other liquids are referred to as dissolved oxygen. Because of its effect on the species that live in a body of water, it is an important parameter in determining water quality. Too much or too little dissolved oxygen can damage aquatic life and degrade water quality. Fish mortality rates will increase if dissolved oxygen concentrations fall below a certain level. Salmon, a sensitive freshwater fish, cannot reproduce at levels below 6 mg/L. Coastal fish begin to avoid areas with DO levels below 3.7 mg/L in the ocean, with certain species leaving an area entirely when levels fall below 3.5 mg/L. Invertebrates leave below 2.0 mg/L, and even benthic species display decreased growth andsurvival rates below 1 mg/L [43].

2. Biochemical Analysis

- **Hardness:** Polyvalent cations (ions with a charge greater than +1) in water are measured by hardness. Since calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions are the most common polyvalent cations, hardness is usually expressed in terms of their concentration. Other ions, such as iron (Fe^{2+}) and manganese (Mn^{2+}), too can contribute to water hardness, although in far lower concentrations. Water with a high hardness value is called "hard," whereas water with a low hardness value is termed "soft". Since calcite (CaCO3) dissolves and releases calcium, hard water is often obtained from the drainage of calcareous (calcite-rich) sediments. As natural water moves through soil and rock containing large quantities of these elements in mineral deposits, calcium, magnesium, and other polyvalent cations such as iron and manganese, are added to the system. If minerals containing these constituents are exposed to air and water, drainage from both active and abandoned mine sites may contribute to polyvalent cations eventually increasing the water hardness. Soft water has a total hardness of 0 to 60 mg/L, moderately hardwater has 60 to 120 mg/L, hard water has 120 to 180 mg/L, and extremely hard water has more than 180 mg/L [44].

- **Biochemical Oxygen Demand (BOD) :** The amount of oxygen absorbed by microorganisms in decomposing organic matter in stream water is measured by biochemical oxygen demand (BOD). The chemical oxidation of inorganic matter is also measured by BOD (i.e., the extraction of oxygen from water via chemical reaction) The amount of dissolved oxygen in rivers and streams is directly affected by BOD. The higher the BOD, the faster the oxygen in the stream is drained. This suggests that higher levels of marine life have less oxygen available to them. A test is

used to determine how much oxygen these species absorb over a given period (usually 5 days at 20°C). Leaves and woody debris, dead plants and animals, animal manure, effluents from pulp and paper mills, wastewater treatment plants, feedlots, and food-processing plants, inadequate treatment plants, and urban stormwater runoff are all potential sources of BOD. Temperature, pH, the presence of certain types of microorganisms, and the type of organic and inorganic content in the water all influence the rate of oxygen consumption in a stream. High BOD has the same effects as low dissolved oxygen: marine animals become stressed, suffocate, and eventually die. BOD levels vary widely; in general, pure waters have a value of less than 1 mg per litre, moderately polluted waters have a value of 2–8 mg per litre, and treated urban sewage has a value of 20 mg per litre. The discharge of effluent from WWTPs is controlled at a concentration of 20–30 mg per litre and requires a minimum flow in receiving waters to ensure adequate dilution [45].

- **Chemical Oxygen Demand (COD)** - Chemical Oxygen Demand (COD) is a method for quantifying how much oxygen can be drained from a receiving water body due to bacterial activity. The BOD test uses a population of bacteria and other microorganisms to try to replicate what will happen in a natural stream over five days, while the COD test uses a powerful chemical oxidizing agent (potassium dichromate or potassium permanganate) to chemically oxidize the organic material in a wastewater sample under conditions of heat and strong acid. When it comes to biodegradable organics, the COD is usually 1.3 to 1.5 times the BOD as chemical oxidation of organic compounds is more efficient than biological oxidation. When the COD test results are more than twice as high as the BOD test results, there's a fair chance that a large portion of the organic material in the sample isn't biodegradable by ordinary microorganisms [46]. This involves chemicals that are harmful to biological life, making COD tests very useful when analyzing water because BOD testing will bypass them.

- **Nitrate:** The presence of high levels of nitrate in wastewater poses significant risks that can negatively impact water quality and the surrounding ecosystem. Excess nitrate can result in a decline in water quality, rendering it unsuitable for food preparation, especially for infants who are highly susceptible to methemoglobinemia or "blue baby syndrome." Furthermore, nitrate pollution is a major contributor to eutrophication, an ecological disturbance characterized by excessive growth of algae and aquatic plants due to an overabundance of nutrients. This phenomenon can lead to reduced oxygen levels in aquatic environments, posing a serious threat to the well-being of marine organisms and disrupting ecological systems eventually making it unsafe for consumption.

- **Phosphate:** Phosphate overload is an important driver in the degradation of water quality, as it leads to the excessive presence of phosphate in wastewater. Significantly, it functions as an optimal nutrient reservoir for algae, hence facilitating the proliferation of algal blooms within aquatic ecosystems. These blooms have the dual effect of diminishing water clarity and producing chemicals that pose a threat to both aquatic species and human health.

- **Suphate:** Having high levels of sulphate in water can cause significant issues that affect the quality and sensory characteristics of the water. Water that contains elevated levels of sulphate can have an unpleasant smell and taste, making it unappealing for consumption. Additionally, sulphate in water can encourage the growth of sulfate-reducing bacteria such as *Desulfovibrio* species, which can produce hydrogen sulphide gas that has a distinct odour resembling rotten eggs. This gas can also corrode water infrastructure, leading to costly repairs and maintenance

- **Ammonical Nitrogen:** The quantification of ammonical nitrogen in aqueous solutions is a pivotal parameter, as heightened concentrations can give rise to a multitude of deleterious outcomes. Elevated concentrations of ammonium have been observed to exhibit notable toxicity towards aquatic organisms, particularly fish, by impeding their respiratory processes and potentially leading to mass mortalities within fish populations. Furthermore, heightened levels of ammonium can induce alterations in the pH of water due to the process of nitrification that ammonium undergoes, thereby impacting the holistic well-being of aquatic ecosystems. The ramifications stemming from an overabundance of ammonium in aquatic ecosystems transcend the mere influence on aquatic organisms exclusively. This compound has the potential to impose considerable stress on wastewater treatment facilities, leading to diminished operational efficacy and escalated operational expenditures. The presence of wastewater containing high levels of ammonium poses a significant challenge to the treatment processes employed in these facilities, thereby impeding their capacity to efficiently eliminate contaminants and uphold the prescribed water quality benchmarks. Consequently, the aforementioned circumstances require the implementation of more comprehensive treatment protocols, augmented chemical concentrations, and intensified operational endeavours, all of which collectively contribute to escalated operational expenditures. Therefore, the proficient regulation of ammonium concentrations in wastewater is not solely imperative for the preservation of aquatic ecosystems, but also for the enhancement of efficiency and economic viability of wastewater treatment facilities.

3. Microbiological Analysis

- **Most Probable Number (MPN) Test:** Detect the coliform level where coliform acts as an indicator for fecal contamination. This test comprises 3 steps i.e., presumptive test, confirmed test, complete test.

- **Standard Plate Count (SPC) Test:** Method indicates the number of bacterial colonies growing on nonspecific solid nutrient agar (medium) after a given period of incubation.

- **Defining the Quality of Water:** There are certain standard values to which the parameters in water quality are compared in order to determine the status of the water and thus what measures need to be taken in order to convert the wastewater to reusable water. The CPCB (Central Pollution Control Board) has enlisted the standard values w.r.t parameter for comparing the quality of water samples.

4. **Effects on Public Health:** The consequences of water contamination pose a significant threat to public health in a world where the scarcity of clean water is an escalating global concern. Disturbing statistics underscore the immense toll of contaminated water sources on human well-being. Annually, nearly one million lives are claimed by waterborne diseases, underscoring the dire consequences of insufficient access to clean water. Additionally, an astonishing 2.4 billion individuals, constituting one-third of the global population, confront the challenge of inadequate sanitation facilities, rendering them vulnerable to afflictions like cholera, typhoid fever, and various waterborne illnesses [47]. An influential study released by the American Academy of Microbiology stands as a compelling call to action against complacency in wastewater treatment. Entitled "A Global Decline in the Microbiological Safety of Water: A Call for Action," this report highlights the inextricable link between water and infectious diseases, revealing that an astonishing 80 percent of such maladies are associated with water [48]. Among these, diarrheal diseases, primarily originating from tainted water sources, exact a devastating toll, claiming the lives of around 2 million children annually and inflicting 900 million cases of illness [49].

Of particular note, the report's findings emphasize that microbiologically safe drinking water can no longer be taken for granted, even within developed countries. Recent large-scale outbreaks of waterborne diseases, such as cryptosporidiosis in the United Kingdom, Canada, and Milwaukee, Wisconsin, underscore the gravity of this global crisis. Cryptosporidiosis, caused by microorganisms present in water contaminated by human or animal waste, resulted in significant casualties in Milwaukee in 1993 [50]. While many waterborne illnesses in the United States are linked to individual wells or small community networks, the overarching threat remains pervasive.

Transmission of waterborne diseases occurs through various pathways, including direct contact with sewage, consumption of contaminated food or water, or interaction with human, animal, or insect carriers. It is crucial to recognize that a substantial portion of wastewater, whether treated or untreated, ultimately finds its way into natural water bodies, such as rivers, streams, lakes, and oceans, sometimes through groundwater. This dispels the misconception that groundwater is inherently pure. Furthermore, waterborne illnesses encompass a spectrum of symptoms extending beyond diarrhea and vomiting to include skin, ear, respiratory, and eye ailments. Some such waterborne diseases are discussed as follows and listed in Table 2.

- **Diarrhea:** Diarrhea stands as a prevalent symptom resulting from diverse infections caused by various pathogenic species, many of which are transmitted through feces-contaminated water sources. The risk of infection escalates in settings marked by inadequate sanitation, hygiene practices, and access to clean water for drinking, cooking, and hygiene maintenance. Notably, *Rotavirus* and *Escherichia coli* rank among the most common etiological agents responsible for moderate-to-severe diarrhea in low-income countries. Additionally, *Cryptosporidium* and *Shigella species* represent other significant pathogens in this context. The clinical presentation of diarrhea encompasses symptoms such as dizziness, dehydration, pallor, and, in severe instances, loss of consciousness. Typically, diarrhea is of short duration, lasting only a few days. Clinical diarrhea can be categorized into three primary types: acute watery diarrhea, which persists for several hours or days and includes cholera, acute

bloody diarrhea, also referred to as dysentery, and persistent diarrhea, which extends for 14 days or longer [49].

- **Typhoid:** Typhoid fever, also known as enteric fever, is primarily caused by *Salmonella enterica* serotype typhi and, to a lesser extent, *S. enterica* serotypes *paratyphi A, B,* and *C*. This disease exhibits a spectrum of clinical manifestations, ranging from severe multisystemic infections to mild cases featuring diarrhea and a low-grade fever. Common symptoms encompass fever, malaise, diffuse abdominal pain, and constipation. Left untreated, typhoid fever can lead to delirium, obtundation, intestinal hemorrhage, bowel perforation, and fatality within a month of onset. Survivors may experience enduring or lifelong neuropsychiatric sequelae. Typhoid is recognized for its high degree of contagiousness. *S. typhi* possesses a Vi capsular antigen that conceals pathogen-associated molecular patterns (PAMPs) and impedes neutrophil-mediated inflammation, unlike *paratyphi A*. The infection route involves traversal through the mesenteric lymph nodes, the thoracic duct, and lymphatics, ultimately reaching reticuloendothelial tissues found in the liver, spleen, bone marrow, and lymph nodes. Here, the bacteria multiply until reaching a critical density, leading to macrophage demise, permitting their entry into the bloodstream and systemic infection. Subsequently, the gallbladder becomes infected through bacteremia or direct extension of infected bile, with the organism re-entering the gastrointestinal tract via the bile and re-infecting Peyer's patches. Bacteria not re-infecting the host are typically excreted in stool, posing a risk of transmission to other individuals. Typhoidal salmonella skillfully utilizes the cellular machinery of macrophages for replication [51].

- **Giardiasis:** Giardiasis emerges as a prevalent diarrheal disease with a global footprint. Its causative agent, the flagellate protozoan *Giardia intestinalis* (formerly *G. lamblia* or *G. duodenalis*), ranks as the most widely recognized intestinal parasite in the United States and the most commonly isolated protozoal intestinal parasite worldwide. Children exhibit heightened susceptibility to infection compared to adults. *G. intestinalis* can elicit asymptomatic colonization or manifest as acute or chronic diarrheal disease. This organism has been detected in up to 80% of untreated water sources originating from lakes, streams, and wetlands, as well as up to 15% of filtered water samples. In infants, it represents a common cause of chronic diarrhoea and growth retardation [52].

Table 1: List of Waterborne Diseases and Pathogens Involved in it

LIST OF WATERBORNE DISEASES				
Disease	**Pathogen Involved**		**Disease**	**Pathogen Involved**
Typhoid	*Salmonella typhi* (bacteria)		**Cholera**	*Vibrio cholerae*
Diarrhoea	Salmonella spp. Campylobacter Shigella *Enterotoxigenic E.*		**Dysentery**	Salmonella spp. Campylobacter Shigella *Enterotoxigenic E. coli*

	coli Rotavirus Cryptosporidium			
Giardia	*Giardia duodenails*	**Hepatitis A**	*Hepatitis A virus*	
Leptospirosis	Leptospira	**Botulism**	*Clostridium botulinseveralum*	
Dengue	Flavivirus	**Trachoma**	*Chlamydia trachomatis*	
Gastroenterit is	Salmonella spp. Campylobacter	**Onchocerci asis**	*Onchocerca volvulus*	
Polio	Poliovirus	**Ascariasis**	*Ascaris lumricoides*	

V. INTRODUCTION TO WASTEWATER TREATMENT

It is surprising that a substantial number of households in both developed and developing countries, including small and rural communities, still lack adequate facilities for the collection, treatment, and disposal of wastewater. Wastewater treatment is as pivotal for community health as other essential services like drinking water treatment, waste disposal, and immunization programs. In regions where wastewater treatment remains inadequate or absent, the potential for disease transmission remains alarmingly high.

The implementation of wastewater treatment systems plays a pivotal role in rendering contaminated water safe and usable. These systems employ various methodologies to eliminate contaminants, encompassing solid waste and chemical pollutants. The four primary methods employed for wastewater treatment are physical treatment, biological treatment, chemical treatment, and sludge treatment. Let's delve deeper into each of these methods.

1. **Physical Wastewater Treatment:** Physical wastewater treatment primarily involves the use of physical processes to cleanse the wastewater. It entails the removal of solids through techniques such as screening, sedimentation, and skimming, without the reliance on chemical agents. Among these techniques, sedimentation stands out as a widely utilized approach, serving the purpose of separating insoluble and heavy particles from wastewater. Another vital physical water treatment method is aeration, which introduces oxygen into the water by means of air injection. Additionally, filtration serves as a pivotal means to eliminate various pollutants by transporting wastewater through specialized filters, with sand filters being particularly popular. This process can also expediently remove grease from the surface of specific wastewater types [53].

2. **Biological Wastewater Treatment**: Biological wastewater treatment involves the breakdown of organic matter present in wastewater, including substances such as soap, human waste, oils, and organic residues, through diverse biological processes. Microorganisms play a central role in metabolizing organic matter found in wastewater.

3. **This Biological Treatmentcan be categorized into Three Key Types**

   - **Aerobic Processes:** These involve bacteria that decompose organic matter and

convert carbon dioxide into aform usable by plants, relying on oxygen for this process.

- **Anaerobic Processes:** Taking place in the absence of oxygen, this method employs fermentation to break downwaste at specific temperatures.
- **Composting:** An aerobic treatment technique, composting involves blending wastewater with materials likesawdust or other carbon sources [54].

4. **Chemical Water Treatment:** Chemical water treatment incorporates the use of chemicals to purify wastewater. Chlorine, a natural oxidizing chemical, is employed to eliminate bacteria responsible for water degradation by introducing pollutants. Another oxidizing agent, ozone, is utilized for wastewater purification. Additionally, neutralization comes into play, entailing the addition of acids or bases to restore water to its neutral pH of 7. Chemicals serve to inhibit bacterial reproduction in water, resulting in clear and sanitized water [55].

5. **Sludge Treatment:** Sludge treatment represents a solid-liquid separation process, aiming to achieve minimal residual moisture content in the solid phase and minimal solid particle residues in the separated liquid phase. While conventional and non-conventional wastewater treatment methods, such as activated sludge treatment, trickling filters, and wetlands, offer viable solutions, they do come with notable drawbacks, including cost implications, end product considerations, energy consumption, and land requirements, among others [56].
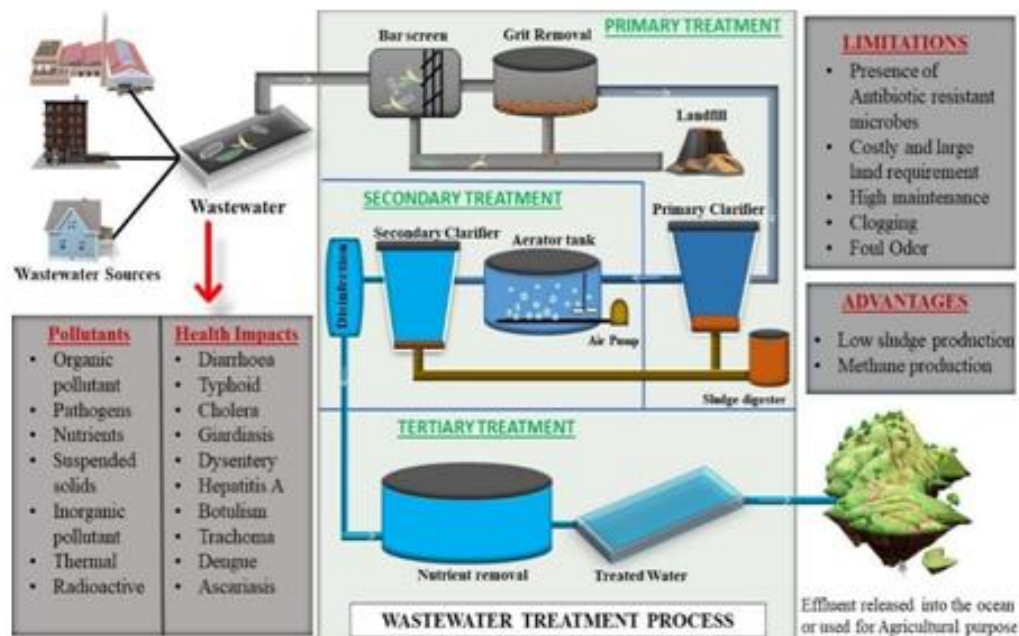

Figure 1: Illustration Showing the Source of Contaminant and Wastewater Treatment Process Along with its Advantages and Disadvantages.

Wastewater treatment typically comprises a tripartite sequence, encompassing primary, secondary, and tertiary treatment phases. The primary phase primarily addresses

the elimination of larger particles, while the secondary phase is chiefly dedicated to the removal of organic substances. Despite the application of primary and secondary treatments, residual undesirable constituents persist in the treated water. Consequently, tertiary treatment is employed as a refining unit to eliminate these remaining contaminants. These treatment procedures generally incorporate an amalgamation of diverse physical, chemical, and biological processes [57].

- The **primary treatment** process encompasses a dual-stage approach, namely preliminary treatment andthe sedimentation process [57]. In the preliminary treatment phase, various mechanisms such as screening, grit chambers, and skimming tanks are employed to eliminate sizeable particles, debris, oil, and fats from the wastewater. Subsequently, the wastewater undergoes sedimentation or chemical precipitation within primary settling tanks, resulting in the removal of organic solids, colloidal matter, and finer suspended particles in the form of sludge.

  The initial stage of wastewater treatment involves the removal of entrained large, floating, or suspended solids, which may encompass materials such as wood, plastic, cloth, and paper. Screening serves as a crucial process with dual objectives: safeguarding other mechanical equipment and averting the blockage of valves and associated components within the wastewater treatment facility [58]. Screens are configured in a rectangular shape with uniformly sized openings created through perforated metal plates. These screens are strategically positionedat an inclined angle (ө) typically ranging from 30° to 60° concerning the direction of wastewater flow [59]. Various screen types are available, categorized by the size of their openings, including coarse, medium, and fine screens.

  The **grit chamber** serves as an extended, narrow, rectangular channel or elongated basin, functioning as a sedimentation tank tasked with two primary objectives: the elimination of denser inorganic materials and the onward transmission of lighter organic materials for subsequent processing stages. Its design is centered around regulating the velocity of wastewater flow to facilitate material removal. In cases where the flow rate is either too low or too high, it can lead to the settling of lighter organic substances or even the complete settling of grit particles. To maintain a consistent flow velocity, a velocity control apparatus known as the "proportional flow weir" is positioned at the outlet of the grit chamber. Various types of grit removal chambers are deployed in wastewater treatment plants, such as aerated grit chambers, vortex-type grit removal systems, detritus tanks, and horizontal flow grit chambers, selection being contingent on the specific characteristics of the wastewater. [60-61]

- In the **secondary treatment stage**, biodegradable soluble organic compounds undergo degradation through the action of microorganisms [62]. Specifically chosen microorganisms are introduced into the wastewater, where they thrive by consuming organic matter in the presence of oxygen. Biochemical oxygen demand (BOD) is commonly used as a metric to assess wastewater quality. As organic substances are progressively removed, the BOD level decreases [63]. These biological treatment methods can be classified into two main systems: suspended growth and attached growth systems.

The **suspended growth system** is a technique that utilizes microorganisms that float freely in wastewater and form biological flocs. These flocs consist of bacteria that can purify the wastewater. Some well-known suspended growth systems include aerated lagoons and activated sludge. On the other hand, the attached growth method involves using materials like gravel, ceramic, or plastic to cultivate microorganisms. These materials are exposed to wastewater, causing biofilms to grow and thicken over time until they detach during sloughing. Attached-growth systems offer significant advantages over suspended-growth systems. These systems are easier to operate, require less equipment maintenance, and use less energy. However, they may have certain limitations when it comes to managing large volumes of wastewater, require more space, and have odor issues.

Following the introduction of specific microorganisms, namely aerobic bacteria, into this system, the sewage surface becomes oxygenated [64]. These aerobic bacteria utilize oxygen to facilitate the oxidation of organic substances that are prone to decomposition. This oxidation process leads to the formation of a bacterial film or slime layer on the sewage surface. As the organisms within this film adsorb further organic material and agglomerate it, the film gradually settles down.

Trickling filters use different materials like slag, coke, gravel, ceramic, and polyurethane foam. These materials have a large specific surface area, which allows a strong biofilm to grow on their surface. This biofilm fosters the growth of aerobic bacteria, which effectively purify the wastewater as it flows through the filter's base. The wastewater is evenly distributed across the material bed with the help of a rotating arm. Finally, the purified water is released as effluent [65].

In contrast, **rotating biological contactors** (RBC) have 40 percent of their surface area covered by closely spaced polymeric circular discs set on a rotating shaft. These discs are inhabited by microorganisms, which when above water take in oxygen and when below water take in organic compounds. Numerous organic chemicals are successfully removed from the wastewater using this procedure [66].

The method known as the **activated sludge** process is a widely used technique to eliminate residual suspended and colloidal solids from wastewater following initial sedimentation. In this approach, the suspended solids act as a foundation for diverse biological entities, including bacteria, to develop and form larger solids [67]. The final product, the activated sludge, takes on a floc-like appearance and has a brownish hue, with a high level of organic matter derived from the wastewater and teeming with a diverse array of microorganisms. This biologically active sludge absorbs or adsorbs colloidal and dissolved organic compounds, which act as a food source for the indigenous biological entities. These organisms then convert these ingested substances into inert, insoluble solids, while simultaneously producing new bacterial cells. According to a study [68], some bacteria generate uncomplicated compounds while decomposing intricate ones. Subsequently, other bacterial clusters take over and further metabolize these byproducts until they are no longer viable as a nutrient source. To maintain the activated sludge's efficiency, it must be kept suspended in the wastewater throughout the treatment cycle and prevented from settling at the bottom, which can be accomplished by continuous agitation.

Aerated lagoons, a wastewater treatment modality, predominantly rely on mechanical or diffused aeration for oxygenation, distinguishing them from systems dependent on algal photosynthesis. Their classification hinges on mixing capabilities, with partial mix variants meeting oxygenation requisites but failing to sustain total suspended solids in suspension. Well-suited for treating low to moderately concentrated municipal and industrial wastewaters, aerated lagoons offer notable advantages. These include diminished land requisites compared to facultative lagoons and ponds, the capacity for year-round discharge in frigid climates, and relatively modest sludge disposal demands. However, they exhibit limitations such as reduced efficacy in ammonia nitrogen and phosphorus removal unless tailored for nitrification, susceptibility to surface ice formation, diminished biological activity during cold spells, potential issues with insect vectors in the absence of proper vegetation upkeep, and heightened sludge accumulation rates in colder settings due to the inhibition of anaerobic reactions.

Additionally, the operation of aerated lagoons necessitates energy inputs [69]. Other techniques used in the secondary treatment stage include disc contractors, extended aeration, and high rate activated sludge.

- **Tertiary Treatments**, often referred to as advanced treatment methods, constitute a pivotal stage in wastewater treatment by targeting the substantial removal of phosphorus, nitrogen, biodegradable organic matter, heavy metals, viruses, and pathogenic bacteria. Numerous advanced treatment techniques have been devised, encompassing methods such as disinfection, membrane separation, and electrodialysis etc.

  ➢ **Disinfection:** Disinfection, primarily employed in municipal water treatment at the tertiary level, involves the eradication of pathogenic microorganisms like bacteria and viruses through the introduction of specific chemicals, such as chlorine-based disinfectants [70]. Chlorination can be executed by adding bleaching powder or infusing chlorine gas, effectively eliminating most pathogenic microorganisms. Alternatively, UV radiation has gained prominence for its disinfection capacity. UV light functions by altering the biological components of microorganisms, disrupting chemical bonds in DNA, RNA, and proteins, and curtailing regrowth potential withinthe distribution system

  ➢ **Electrodialysis:** The electrodialysis procedure effectively removes both cations and anions from water by utilizing an externally applied voltage to drive ion migration through ion-exchange membranes [71]. The conventional electrodialysis unit consists of a cation-selective membrane, an anion-selective membrane, and electrodes positioned between them. During the process, anions move towards the anode while cations migrate towards the cathode, resulting in purified water. It's crucial to note that this technique can connect more than 500 units, makingit an incredibly flexible method for purifying industrial water [72].

  ➢ **Reverse Osmosis (RO):** In the realm of membrane separation, reverse osmosis (RO) emerges as a vital method to eliminate inorganic minerals like calcium, magnesium, sodium, potassium, phosphorous, fluoride, and organic compounds,

including pesticides. In the RO process, wastewater undergoes treatment through a semi-permeable membrane under the influence of osmotic pressure, effectively removing impurities while allowing water to pass through. Commonly used RO membranes, such as cellulose acetate and polyamide, play a pivotal role in wastewater purification [73].

➢ **Photocatalysis:** One effective way to remove water contaminants is through the process of photocatalysis. This method utilizes sunlight and is an affordable, environmentally friendly, and easily accessible approach. Photocatalysis can break down a range of substances including organic molecules, colors, crude oils, microbes, and even inorganic elements like nitrous oxide. When combined with precipitation and filtration, photocatalysis becomes a powerful tool for removing heavy metals from water [74]. Titanium dioxide, or TiO2, is a semiconductor photocatalyst utilized for reducing and removing harmful substances from wastewater. This method proves effective for treating different types of wastewaters, including those from garage forecourts [75]. However, it has a limitation when it comes to efficiently dealing with highly concentrated organic pollutants, which is one of its significant disadvantages.

A summary of various treatments is given in TABLE 3 as follows:

Table 3: Summary of various wastewater Treatments (Gedda, G., Balakrishnan, K., Devi, R. U., Shah, K. J., Gandhi, V., Gandh, V., & Shah, K. L. (2021). Introduction to conventional wastewater treatment technologies: limitations and recent advances. Mater. Res. Found, 91, 1-36.)

Treatment Types	Advantages	Disadvantages
Coagulation	• Low principal cost • Effortless procedure	• Generating a large quantity of sludge
rickling filters	• Capability to remove the high quantity of the BOD • Efficiency in treating a large amount of organic matter • Remarkable ability to remove ammonia • Creates a low amount of sludge • High skilled and technical expertis is not required to operate and manage the system	• High principal cost • Blocking of rotating arms • High intense odor generation
Rotating Biological contactors	• Aeration *via* atmosphere • Affordable operation cost • Generation of low quantity of sludge	• A huge area is necessary for thissystem • Protection of the system in a cold climate is difficult

Activated sludge process	- Aeration *via* atmosphere - Available in domestic toindustrial scale - Feasible to remove the high quantity of the BOD, COD, nitrogen, and phosphorous. - Simple operating system - Ability in producing electric energy from biogas - Excellent effluent quality	- Concentration the of sludge to be monitor - Operation cost
Disinfection (Bleaching powder / Cl_2 treatment)	- Low cost and readily available - High water solubility - Toxic to pathogens - Potential to remove a high quantity of the iron, manganese and ammonia nitrogen during oxidation	- Corrosive - Difficult to handle Cl_2 gas due to its hazards nature
Reverse Osmosis	- Available in domestic toindustrial scale - The efficient rejection rate ofsalt, organic compounds, and pathogens. - The low quantity of energy is sufficient - Membranes can be replacedeasily - Easy to maintain	- The problem in large scale treatment due to sludge generation - Pre-treatment is essential before purifying the water - Membranes are highly sensitive topH
Electrodialysis	- High selectivity of ions - Regeneration of membrane iseasy - Pre-treatment of water not necessary	- Operational cost ishigh - Ions only can beremoved - Based on water quality, the membrane needs to be selective

VI. CONCLUSION

In conclusion, this chapter serves as a beacon of knowledge in our quest to address the pressing issue of wastewater treatment. It has taken us on a profound journey through the intricate world of wastewater, revealing its diverse sources, complex composition, and far-reaching consequences. The chapter also focuses upon the environmental and public health risks associated with improper wastewater management, underlining the urgency of finding effective solutions. The field of wastewater treatment is also currently encountering several obstacles, including limited capacity, a scarcity of trained professionals, high energy usage, over-reliance on chemicals, and challenges regarding the management of sludge. To tackle these challenges, researchers are exploring advanced wastewater treatment technologies, such as nanomaterials, oxidation techniques, superior sludge management, cost-effective adsorption materials, and membrane technology. Despite these advancements, there are still gaps in our understanding that require further research. By integrating these innovative

technologies with traditional methods, wastewater can be more effectively treated. The journey continues, but with newfound knowledge and purpose, we are better equipped to navigate the complex waters of wastewater treatment and emerge as champions of a cleaner, healthier world.

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