Journal of Xi'an Shiyou University, Natural Science Edition ISSN: 1673-064X

Non-Plastic Waste in Water Bodies and the Role of Wastewater Treatment in Achieving Sustainable Development Goals (SDGs)

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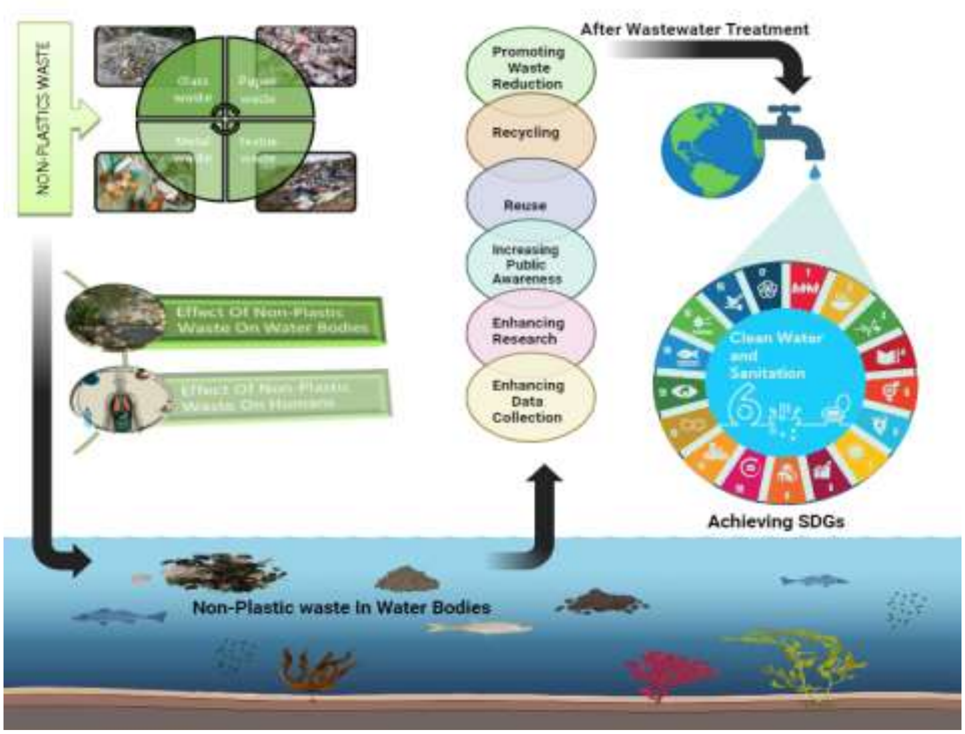
Abstract

This study explores the environmental impacts of non-plastic waste in water bodies, an often-understudied area of water pollution research. While plastic waste has been the focus of environmental concern, other forms of waste also play a significant role in the degradation of aquatic ecosystems. This includes waste products such as glass, metal, paper, textiles, and chemical pollutants. Non-plastic waste materials can alter the physical characteristics of water bodies, disrupt the balance of aquatic ecosystems, and introduce toxic elements that have far-reaching impacts on both local and global scales. This review employs a multi-disciplinary approach, combining principles from environmental chemistry, ecology, and hydrology to provide a comprehensive understanding of the issue. The paper reviewed the chemical and physical properties of different types of non-plastic waste and investigated their specific impacts on aquatic life and water quality. The global community has adopted the sustainable development goals (SDGs), which the world is currently working to achieve. For the decision-makers, understanding how technology can help achieve the SDGs is essential because it will enable them to overcome any potential trade-off. The contribution of wastewater management to the SDGs has been highlighted in this work. According to the analysis, treating wastewater could help achieve 11 of the 17 Sustainable Development Goals directly and all others indirectly.

Keywords: Non-Plastic waste, Wastewater Treatment, Aquatic ecosystems, SDGs, Plastic waste

Graphical Abstract



1. Introduction

The deterioration of water bodies due to waste disposal is a pressing global issue, threatening the health of aquatic ecosystems, as well as human health and economic development (Derraik, 2002). The sources of water pollution are numerous, ranging from industrial waste and agricultural runoff to municipal waste disposal. Among these pollutants, plastic waste has received significant attention due to its pervasiveness and longevity in the environment (Andrady and Neal, 2009).The proliferation of plastic waste in water bodies has been the subject of numerous studies, demonstrating its detrimental impacts on aquatic life (Rochman, 2013) and contributing to the growing 'plastic soup' problem in the world's oceans (Eriksen *et al.*, 2014). Media coverage and public discourse have echoed this concern, often framing plastic waste as the primary culprit in the pollution of water bodies. Governmental and non-governmental entities alike have launched numerous initiatives targeting the reduction of plastic waste, often focused on single-use plastics (Xanthos and Walker, 2017).

While the attention given to plastic waste is undeniably important, we noticed a significant gap in our understanding of the environmental impacts of non-plastic waste products such as glass, metal, paper, textiles, and chemical pollutants in water bodies (Zambrano-Monserrate and Ruano, 2020) which can also have far-reaching impacts on aquatic environments. Additionally, the interplay of different waste types in water bodies and their combined effects on aquatic ecosystems is another area that remains understudied. Most studies tend to focus on a single waste material or pollutant, but in reality, aquatic ecosystems are often exposed to a mix of pollutants (Schwarzenbach *et al.*, 2010) understanding how these pollutants interact and their cumulative impacts could provide valuable insights for managing water pollution.

Diseases spread by wastewater include cholera, typhoid, dysentery, and diarrheal diseases which kill millions of people each year and are caused by a lack of sanitation. Therefore, there are serious risks to human health and the environment when untreated wastewater is disposed of haphazardly and ends up in water resources (Tariq and Mushtaq, 2023). The heterogeneity and complexity of all the contaminants provide challenges for this wastewater treatment, necessitating the use of highly effective methods to achieve the required water quality standards. The Global Sustainable Development Goals, or SDGs, of the United Nations mandate that by 2030, everyone should have adequate access to safe drinking water (Water *et al.*, 2018). According to the most recent United Nations statistics, most nations are still making inadequate progress toward accomplishing this objective. It is essential to recognize the potential dangers posed by untreated wastewater, as it can have detrimental effects on both public health and economic resources due to its significant impact on receiving water bodies and associated operational expenses (Tariq and Mushtaq, 2023). Consequently, effective water treatment emerges as a pivotal element in ensuring sustainable water management practices.

The recovery and reuse of valuable byproducts open up new economic opportunities and can pave the way for the development of the circular economy through wastewater management (Sharma *et al.*, 2021). Throughout the years, the environment has undergone constant change, and human growth has had an effect on society as a whole. The negative effects on the environment and society have been mostly caused by urbanization and industrialization. It has therefore prompted the need for broad-based management (Nathaniel, 2021). A shift toward sustainable development is now essential in many ways because societies all over the world are dealing with a variety of environmental concerns. A great deal of attention must be paid to sustainable development in addition to identifying and halting actions that are detrimental to society (Fallah Shayan *et al.*, 2022). Governments nowadays are very concerned about the challenges and harm that companies and individuals are causing to the environment and society. Besides, the relevant organizations have favorably contributed to a variety of concerns, including wastewater management (Abdelfattah *et al.*, 2023). Given the scarcity of resources, society must ensure that they are used to their optimum potential and place a strong emphasis on sustainable development.

The main objectives of this study are to describe the prevalence of non-plastic pollution in water bodies and their impacts, analyze the significance of wastewater treatment in accomplishing the SDGs and suggestions for improving the advantages of wastewater management within the SDGs. This study commenced by providing an overview of the impacts of plastic waste, wastewater treatment strategies, and the criteria for choosing among the various approaches to accomplish these goals. Additionally, a set of rules and indicators were established to increase the impact of wastewater treatment plants on the SDGs. The suggested metrics would guarantee enhanced sustainability performance of wastewater treatment facilities and optimize their contribution towards the SDGs.

2. Types of Non-Plastic Waste

A significant part of this research focuses on non-plastic waste, which includes a variety of materials such as glass, metal, paper, textiles, and chemical pollutants. Each of these types of waste has distinct properties, making them unique in the way they interact with and impact water bodies.

2.1 Glass Waste

It primarily originates from beverage containers, broken bottles, and other discarded glass items. While glass is inert and does not usually contribute to chemical pollution, it can pose physical hazards to aquatic and terrestrial organisms. Additionally, glass items can take a very long time to degrade fully in the environment, with some estimates suggesting it may take up to a million years for a glass bottle to break down naturally (Barnes *et al.*, 2009). Glass is being overused and produces millions of tons of waste annually. The primary concern, though, is that glass recycling makes up only ¼ of the total quantity of glass produced globally, which is significantly less than the amount of glass that is manufactured.

2.2 Metal Waste

Metal waste in water bodies mainly consists of aluminum cans, tin cans, and other discarded metal items. This type of waste can pose risks due to its potential to leach toxic substances into the environment. For instance, aluminum can leach from cans into water, especially under acidic conditions, and may have toxic effects on aquatic organisms (Bryan *et al.*, 1985). Furthermore, metal items can be a physical hazard, causing injury or entanglement, and like glass, they are highly persistent in the environment, with aluminum cans estimated to take 200 to 500 years to decompose completely (Barnes *et al.*, 2009).

2.3 Paper Waste

Paper waste, which is often assumed to be harmless due to its biodegradability, can nonetheless contribute to water pollution. While paper does decompose relatively quickly compared to materials like glass or metal, it can still cause substantial short-term pollution, particularly when large amounts of paper waste end up in water bodies (Van Cauwenberghe *et al.*, 2013). Additionally, paper products often contain dyes, inks, and other chemicals that can leach into water and contribute to chemical pollution (Esa *et al.*, 2014).

2.4 Textile Waste

Textile waste includes both macroscopic items, such as discarded clothing or fabric, and microscopic fibers that are shed from textiles during washing. These fibers, often made from synthetic materials, are highly persistent in the atmosphere and can be ingested by aquatic organisms, leading to potential physical harm or exposure to associated chemicals (Browne *et al.*, 2011). There are various steps involved in the processing of textiles, the most crucial being wet processing. Large volumes of textile effluent are produced during wet processing since it uses a lot of water and chemicals. When textile effluents are dumped in open spaces or near water bodies, they contaminate the surrounding land and water.

2.5 Chemical Pollutants

Chemical pollutants represent a broad category of non-plastic waste that range from heavy metals, such as lead or mercury, to organic compounds like pesticides, pharmaceuticals, or industrial chemicals. Chemical pollutants can have a variety of effects on aquatic ecosystems, including toxicity to aquatic organisms, disturbance of biological processes, and long-term accumulation in the environment and organisms (Schwarzenbach *et al.*, 2010). They can enter water bodies through various pathways, including industrial discharge, agricultural runoff, and urban wastewater, and their detection in water bodies worldwide has been widely reported (Fatta-Kassinos *et al.*, 2011).

3. The Prevalence of Non-Plastic Waste in Water Bodies

In an era characterized by rapid industrialization, urbanization, and increasing consumption, the production of non-plastic waste has escalated at an alarming rate. These wastes, when improperly managed, often find their way into our rivers, lakes, and oceans, leading to a myriad of environmental problems (Ballent *et al.*, 2016) The prevalence of non-plastic waste in water bodies is significant, as revealed by several studies that have endeavored to quantify it. In terms of glass waste, for instance, studies have shown that this material, often in the form of beverage containers or fragments thereof, is a common type of debris found in aquatic environments. A study carried out by Williams and Simmons (1997) along the coast of England found that glass items constituted **approximately 14%** of all litter items. Similarly, a survey conducted in the Mediterranean Sea revealed that glass items made up **around 17%** of the marine little (Topçu *et al.*, 2013).

Metals, particularly in the form of discarded cans and other containers, are also prevalent in water bodies. Metal waste can be harmful due to its potential to leach toxic substances, such as lead or aluminum (Bryan *et al.*, 1985). For example, A study found that metal items, predominantly aluminum drink cans, comprised **about 8%** of total litter items in the River Thames in England (Blair *et al.*, 2019).Textile waste is another often overlooked contributor to water pollution. These small fibers can pass through wastewater treatment plants and end up in rivers, lakes, and oceans (Hartline *et al.*, 2016). It was found that microfibers made up approximately 85% of human-made trash on shorelines around the world (Browne *et al.*, 2011).

These pollutants include a wide range of substances such as pesticides, pharmaceuticals, heavy metals, and industrial chemicals, among others. These substances can enter water bodies through various pathways, including industrial discharge, agricultural runoff, and urban wastewater (Schwarzenbach *et al.*, 2010). The presence of these pollutants in water bodies has been widely documented, with numerous studies reporting their detection in rivers, lakes, and marine environments worldwide (Fatta-Kassinos *et al.*, 2011). Their impacts on aquatic ecosystems, as well as their potential to affect human health, underline the importance of addressing non-plastic waste as part of our efforts to combat water pollution.

4. Impacts of non-plastic waste on Aquatic Ecosystems

Non-plastic waste poses a significant threat to aquatic ecosystems worldwide, manifesting in various forms such as glass, metal, paper, and organic materials. Unlike plastic, which receives considerable attention, non-plastic waste often goes overlooked despite its detrimental effects. Addressing the impacts of non-plastic waste is crucial for the preservation of aquatic biodiversity and the sustainability of our water resources (Kyriakopoulos *et al.*, 2022).

4.1 Impacts of Glass Waste on Aquatic Ecosystems

One of the main concerns with glass waste in water bodies is the potential for physical injury to aquatic and terrestrial organisms. For instance, studies have documented numerous cases of birds and mammals getting cut or injured by glass fragments (Kühn *et al.*, 2015). These injuries can lead to infections or can be fatal in severe cases. Moreover, sharp glass fragments can pose a danger to humans, particularly in recreational areas such as beaches and lakeshores. Glass items can also pose a threat to aquatic organisms if they are ingested. Ingestion of glass fragments can cause internal injuries to animals and can lead to impaired feeding, reduced growth, or death (Derraik, 2002). For instance, seabirds and marine mammals, which may mistake small glass fragments for food items, are particularly at risk (Kühn *et al.*, 2015). The challenges associated with glass pollution in aquatic environments are depicted in **Figure 1**, along with the consequences of micro glass on the soil ecosystems, plant interactions, and possible food chain movement.

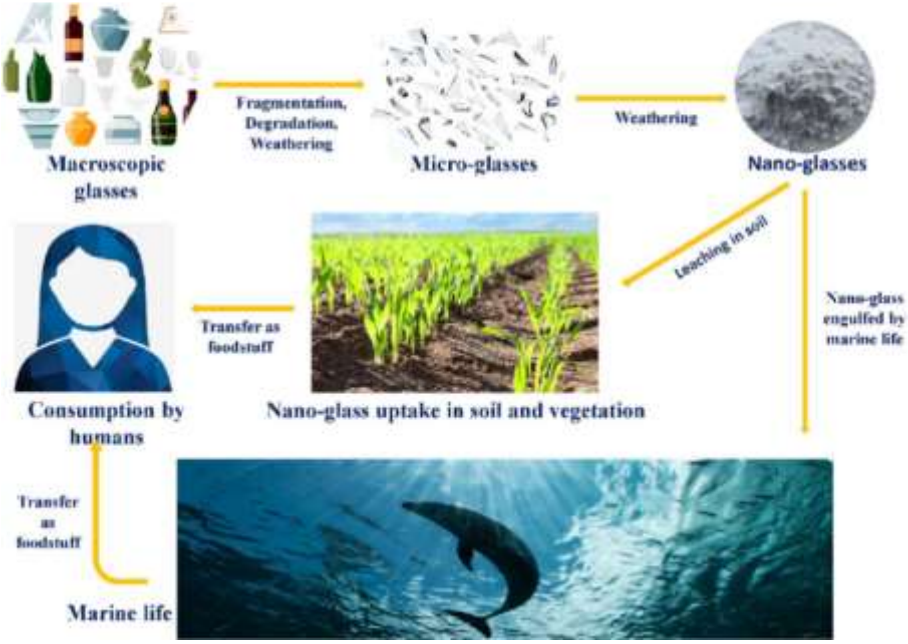


Fig. 1 Overview of micro glass pollution as a significant emerging environmental concern, depicted in a complete chain of its impact. Reprinted with permission from ref. (Kumari *et al.*, 2022) ,Copyright 2024, with permission from Elsevier

Furthermore, while glass is generally inert and does not leach harmful chemicals, colored glass items may contain metal oxides used as colorants, such as chromium, cobalt, or manganese. While these metals are typically encapsulated in the glass matrix and are therefore not readily released into the environment, they could potentially become available under certain conditions, such as acidic pH or after physical weathering of the glass (Selke *et al.*, 2015). Beyond these direct impacts, glass waste can also contribute to other environmental problems. For example, glass items in water bodies can contribute to habitat alteration by covering the substrate or altering the physical characteristics of the environment. This can affect organisms that live on or in the substrate, potentially leading to changes in community structure or biodiversity (Barnes *et al.*, 2009).

4.2 Impacts of Metal Waste on Aquatic Ecosystems

Metal waste, often in the form of aluminum cans, tin cans, and other discarded metal items, can pose significant risks to aquatic environments due to its potential to leach toxic substances into the water. One of the primary concerns with metal waste in water bodies is the potential for chemical pollution. For instance, aluminum can leach from cans into water, particularly under acidic conditions (Bryan *et al.*, 1985). Leached aluminum can have toxic effects on aquatic organisms, impairing physiological processes such as respiration, growth (Exley and Cragg, 2008) and Metals like lead and mercury, often found in electronic waste, can be particularly harmful. These heavy metals can accumulate in the tissues of aquatic organisms, leading to toxic effects and posing risks to predators higher up the food chain, including humans who consume contaminated seafood(Wang *et al.*, 2012). Besides aluminum, other metals such as iron, copper, zinc, and nickel can also leach from metal waste, depending on the type of waste and environmental conditions(Gadd, 2010). These metals can be toxic to aquatic organisms at high concentrations, leading to effects such as reduced growth, impaired reproduction, or mortality (Lapresta-Fernández *et al.*, 2012).

Metal waste can also pose physical hazards to aquatic organisms. Sharp edges on metal items can cause injury or entanglement, leading to physical harm or death (Besseling *et al.*, 2015). Despite the known impacts of metal waste on aquatic ecosystems, there are still significant gaps in our understanding. For instance, more research is needed to understand the fate and transport of different types of metal waste in water bodies, as well as their long-term impacts on aquatic ecosystems. Furthermore, the potential risks associated with the release of various metals from different types of metal waste under different environmental conditions are not fully understood.

Metal waste in aquatic environments also poses risks to human health. For example, humans can be exposed to heavy metals such as lead and mercury through the consumption of contaminated seafood. These metals can have various harmful effects on human health, including neurological damage and impaired development (Clarkson and Magos, 2006) . Moreover, metal waste can have indirect effects on human communities. For instance, debris such as metal cans or fragments can degrade the aesthetic quality of beaches and other recreational areas, potentially affecting tourism and local economies (Gabrielides *et al.*, 1991).To mitigate the impacts of metal waste on aquatic ecosystems, various strategies can be implemented. These include improving waste management practices to reduce the amount of metal waste that enters water bodies, promoting recycling of metal items, and conducting clean-up efforts to remove existing waste. Additionally, regulations can be put in place to limit the use of certain harmful metals in products, and to ensure proper disposal of items containing these metals (Davies *et al.*, 2002) .

4.3 Impacts of Paper Waste on Aquatic Ecosystems

In the journey through the spectrum of non-plastic waste, our focus then turned towards paper waste and its impacts on aquatic ecosystems. Although paper is often regarded as a 'greener' alternative to plastic due to its biodegradability, it can still have significant environmental impacts when improperly disposed of in water bodies. Paper waste, frequently originating from newspapers, cardboard, packaging, and other forms of discarded paper products, is a common sight in many urban water bodies. While paper waste tends to degrade more quickly than plastic, this degradation process can lead to several environmental impacts (Geyer *et al.*, 2017).

One of the main concerns with paper waste in aquatic environments is the leaching of harmful chemicals used in the paper production process. For instance, many types of paper contain inks, dyes, and other chemicals, which can leach into the water as the paper degrades. These substances can be toxic to aquatic organisms, affecting their growth, reproduction, and survival (Wright and Dobbs, 1991). For example, a study (Eichbaum, 2015) found that the leachates from paper waste could cause oxidative stress in aquatic organisms, leading to DNA damage and other harmful effects. The same study also noted that these impacts could be more severe in the presence of sunlight, which can enhance the toxicity of some chemicals. In addition, the degradation of paper waste in water bodies can contribute to the depletion of dissolved oxygen. As paper waste degrades, it is broken down by bacteria in a process that consumes oxygen. This can lead to hypoxic or anoxic conditions, which can be harmful or even lethal to many aquatic organisms (Davies and Mazumder, 2003).

Paper waste can also contribute to the eutrophication of water bodies. The degradation of paper releases nutrients such as nitrogen and phosphorus, which can promote the growth of algae and other aquatic plants. This can lead to algal blooms and other changes in the water body, potentially leading to shifts in community composition or reductions in biodiversity (Kratina *et al.*, 2012). Despite these known impacts, the effects of paper waste on aquatic ecosystems have been relatively under-studied compared to other forms of waste, such as plastic or metal waste. As a result, there are significant gaps in our understanding. For instance, more research is needed to understand the impacts of different types of paper waste on aquatic ecosystems, as well as the long-term effects of paper waste degradation. Therefore, it is crucial to consider paper waste in our efforts to manage water pollution and protect aquatic ecosystems. This research also highlights the necessity of proper waste management strategies to mitigate the impacts of paper waste on aquatic ecosystems. These may include improving waste disposal practices to prevent paper waste from entering water bodies, promoting recycling and composting of paper waste, and encouraging the use of less harmful chemicals in paper production (Kjeldsen *et al.*, 2014).

4.4 Impacts of Textile Waste on Aquatic Ecosystems

Textile waste originates from a variety of sources, including discarded clothing, household textiles, and industrial processes. While some textile waste may be biodegradable, it can still have significant environmental impacts when it enters water bodies. One of the primary concerns related to textile waste in aquatic environments is the release of microfibers. Microfibers are small fibers, typically less than 5mm in length, that can be shed from synthetic textiles during production, use, and disposal (Browne *et al.*, 2011). Once these fibers enter water bodies, they can be ingested by aquatic organisms, leading to physical and chemical impacts on their health.

A study by (Dris *et al.*, 2015) found that microfibers were present in the stomachs of fish and shellfish from various locations, suggesting that these fibers are widespread in aquatic ecosystems. The ingestion of microfibers has been shown to cause physical harm to aquatic organisms, including gut blockage, inflammation, and reduced feeding (Wright *et al.*, 2013). Furthermore, microfibers can also act as carriers for other pollutants, such as heavy metals and persistent organic pollutants, which can become concentrated in the fibers and subsequently bioaccumulate in aquatic organisms (Ziajahromi *et al.*, 2017). This can lead to a range of harmful effects, including reproductive, developmental, and immune system impairments.

4.4.1 Chemical Pollution from Textile Production

Another concern related to textile waste is the release of chemicals used in the textile production process. These chemicals, which can include dyes, solvents, and other additives, can enter water bodies through industrial effluents, stormwater runoff, or leaching from discarded textiles (Fletcher and Goggin, 2001). The release of these chemicals can have various detrimental effects on aquatic ecosystems. For instance, some chemicals used in textile production are toxic to aquatic organisms, while others can cause eutrophication or oxygen depletion in water bodies(Littrell *et al.*, 1998). Moreover, some textile chemicals have been shown to have endocrinedisrupting properties, which can interfere with the reproductive and developmental processes of aquatic organisms (Jobling *et al.*, 1996).

4.4.2 Physical Impacts of Textile Waste

In addition to the chemical and microfiber-related impacts, textile waste can also have physical effects on aquatic ecosystems. Large pieces of textile waste can entangle or smother aquatic organisms, leading to injury or death (Laist, 1997). Furthermore, textile waste can contribute to the clogging of waterways and exacerbate flooding, which can have both ecological and socio-economic impacts (Jakariya *et al.*, 2003). These physical impacts are depicted in **Figure 2**, which shows the entanglement of aquatic organisms and the clogging of waterways caused by textile waste.

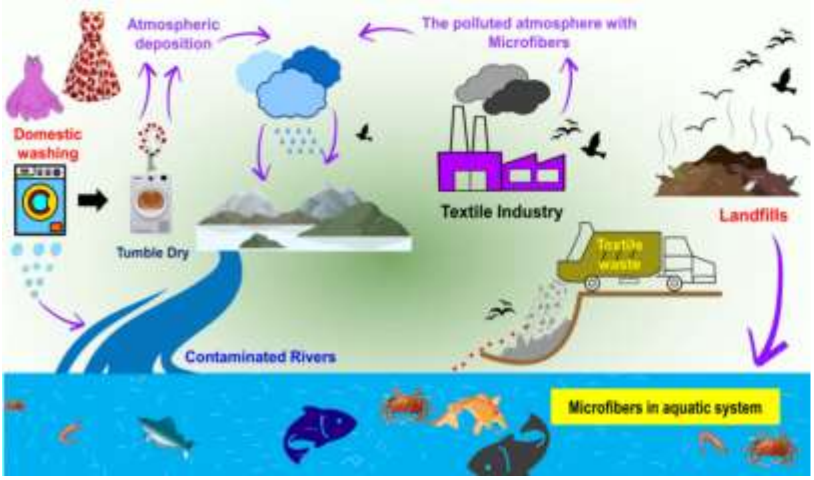


Fig. 2 Primary origins of microfibers in aquatic ecosystems, stemming from activities such as household laundry, textile manufacturing, and the disposal of clothing in landfills from ref. (Periyasamy, 2023) available under a an open access CC BY license, at https://www.mdpi.com/openaccess

4.5 Impacts of Chemical Pollutants on Aquatic Ecosystems

The impacts of chemical pollutants on aquatic ecosystems are influenced by various factors, including the pollutant's properties, environmental conditions, and the characteristics of the affected organisms. Research has shown that chemical pollutants can undergo various transformations in water bodies, such as degradation, sorption, and bioaccumulation, which can influence their environmental fate, bioavailability, and ecological impacts (Arnot and Gobas, 2003). Chemical pollutants can significantly impact biodiversity within aquatic ecosystems. These substances can alter the composition and structure of aquatic communities, leading to a decrease in species diversity and an increase in the dominance of pollution-tolerant species (Karr and Chu, 1999). The alteration of biodiversity can have far-reaching impacts on ecosystem function and stability, underscoring the ecological significance of chemical pollution.

In addition to direct toxicity, chemical pollutants can also have indirect effects on aquatic ecosystems. For instance, chemical pollutants can alter the physical and chemical properties of water, such as temperature, pH, and nutrient concentrations, which can in turn affect the distribution and behavior of aquatic organisms (Dudgeon *et al.*, 2006). Chemical pollutants can interact with other environmental stressors, such as climate change, habitat loss, and overfishing, leading to synergistic or cumulative impacts on aquatic ecosystems (Crain *et al.*, 2008). These interactions can complicate the assessment and management of chemical pollution and highlight the need for a more integrated approach to environmental management.

Despite extensive research on the impacts of chemical pollutants on aquatic ecosystems, there are still significant gaps in our understanding. For instance, more research is needed on the long-term effects of chemical pollution, the impacts of chemical mixtures, and the effects of emerging pollutants such as nanomaterials. Moreover, there is a need for more ecotoxicological research at the ecosystem level to better understand the broader impacts of chemical pollution (Schmaal *et al.*, 2017).

5 Sources and Pathways of Non-Plastic Waste into Water Bodies

Non-plastic waste, such as glass, metals, paper, textiles, and chemicals, can originate from various sources. For instance, waste can come from domestic households, industries, businesses, construction and demolition activities, as well as agricultural practices (Napper *et al.*, 2015). This range of sources adds to the complexity of the issue, as each source type might require different waste management strategies. Industrial activities, for instance, are significant contributors to non-plastic waste pollution. Industries such as textiles, tanneries, pulp and paper manufacturing, and electronic waste recycling can generate large volumes of waste, including heavy metals and toxic chemicals, which can end up in water bodies if not properly managed (Li *et al.*, 2019).

Agricultural activities also contribute to non-plastic waste pollution, particularly in the form of chemical pollutants. The widespread use of fertilizers, pesticides, and herbicides can lead to the contamination of water bodies through runoff, leaching, and soil erosions (Carvalho, 2017). Furthermore, urbanization and rapid population growth have led to increasing amounts of domestic waste. In many developing countries, inadequate waste management systems and the lack of waste segregation at the source can lead to the indiscriminate dumping of waste, including non-plastic waste, into rivers and other water bodies as shown in **figure 3**.

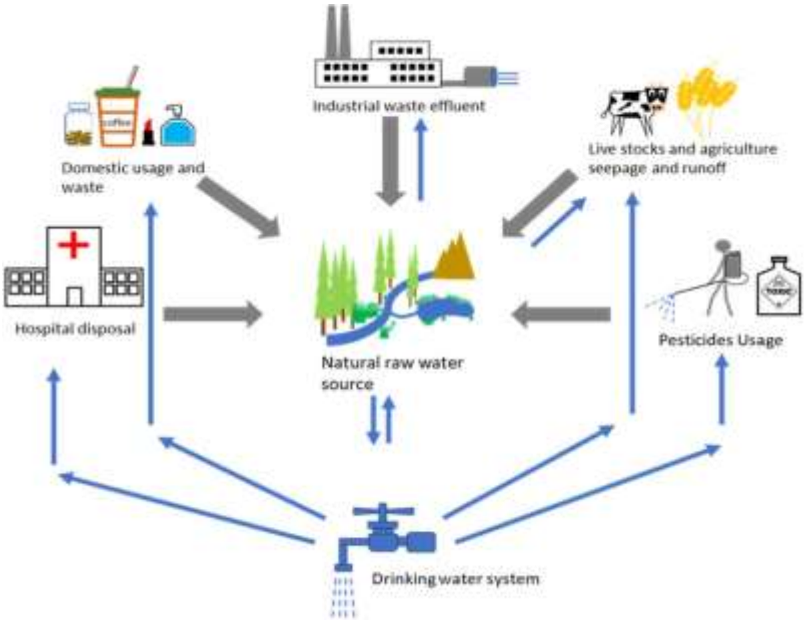


Fig. 3 Pathway and sources of water contamination in the water cycle from ref. (Zhang and Jiang, 2022) available under a an open access CC BY license, at https://www.mdpi.com/openaccess

In addition to these sources, non-plastic waste can also enter water bodies through natural processes such as weathering and erosion. For example, metals can be naturally present in rocks and soil, and can be released into water bodies through weathering processes. Similarly, volcanic activity can release large amounts of metals and other chemicals into the environment, including water bodies (Nriagu, 1989). Once generated, non-plastic waste can find its way into water bodies through various pathways. These can include direct disposal or dumping into water bodies, runoff from land, leakage from waste storage and disposal sites, atmospheric deposition, and discharge from wastewater treatment plants (Unep and ASSESSMENT, 2016).

The sources and pathways of non-plastic waste into water bodies are diverse and complex. The pathway that non-plastic waste takes to enter a water body can greatly influence its potential environmental impact (Osman *et al.*, 2023). For instance, waste that enters a water body through direct disposal or dumping can have immediate and localized impacts, while waste that enters through runoff or atmospheric deposition can have more diffuse and long-term impacts. Urbanization, industrialization, and agricultural practices are not the only contributors to this pressing issue. Other factors like natural disasters, climate change, and human behavior significantly impact the transport of non-plastic waste into our water bodies. For instance, events such as floods and hurricanes can transport large volumes of waste into rivers, lakes, and seas (Derraik, 2002).

Furthermore, climate change can exacerbate these events and increase the likelihood of waste entering water bodies. Human behavior and societal norms also play a significant role in the transport of non-plastic waste into our water bodies. In many regions, waste is often directly thrown into water bodies due to the lack of waste management systems or the ignorance about the harmful impacts of such practices (Hoornweg and Bhada-Tata, 2012). This direct disposal of waste into our rivers, lakes, and oceans is a significant source of non-plastic waste pollution.

Moreover, the waste we generate on land does not stay confined to our neighborhoods and cities. Wind and rain can transport waste into our water bodies. For instance, improperly disposed of waste can be swept into storm drains and eventually end up in rivers and seas. Landfills, especially those located near coasts or rivers, can also contribute to the problem if they are not properly constructed and managed. Leachate from landfills can seep into groundwater or run off into nearby water bodies, carrying with it various types of non-plastic waste (Hamilton *et al.*, 2016). In addition to runoff, non-plastic waste can also enter water bodies through atmospheric deposition. Certain pollutants, such as heavy metals, can be transported through the atmosphere and then deposited into water bodies through rainfall or dry deposition. This is particularly relevant for pollutants that are emitted through industrial processes or combustion of fossil fuels (Mahowald *et al.*, 2008).

6 Interactions and Combined Effects of Different Waste Types

It is increasingly recognized that to fully understand the impacts of waste on aquatic ecosystems, we need to consider not just the individual effects of different waste types, but also their combined and interactive effects (Hoellein *et al.*, 2014). For instance, research has shown that the toxicity of certain chemical pollutants can be magnified in the presence of other pollutants. This phenomenon, known as synergy, can lead to greater-than-additive effects, meaning that the combined effect of two pollutants is greater than the sum of their individual effects (Cedergreen, 2014). This synergistic toxicity can occur between different chemical pollutants, but also between chemical pollutants and other types of non-plastic waste, such as metals (Auta *et al.*, 2017).

On the other hand, certain types of non-plastic waste can interact with chemical pollutants in ways that reduce their toxicity or availability to aquatic organisms. For example, metals can bind to particles in the water, such as those made up of organic matter or clay, reducing their bioavailability and hence their potential toxicity (Di Toro *et al.*, 2001). Similarly, certain types of waste, such as activated carbon or biochar, can adsorb pollutants and reduce their concentrations in the water column (Fatima *et al.*, 2024).

Aside from these chemical interactions, different types of waste can also interact physically, affecting their transport, distribution, and ultimate fate in aquatic ecosystems. For instance, heavier waste materials, such as glass or metal, can sink to the bottom of water bodies, where they can alter the physical structure of the sediment and affect benthic organisms (Browne *et al.*, 2011). On the other hand, lighter waste materials, such as paper or textiles, can float on the water surface and impact surface-dwelling organisms or obstruct sunlight penetration, affecting primary production in the water body (Dris *et al.*, 2015).

Moreover, the presence of one type of waste can influence the effects of another type of waste. For example, research has shown that plastic waste can serve as a transport medium for other types of pollutants, including metals and persistent organic pollutants, enhancing their dispersion in the aquatic environment (Teuten *et al.*, 2009).

7 Current Waste Management Practices

Waste management involves a series of activities that includes compilation, transportation, processing, recycling, and discarding of waste materials (Hoornweg and Bhada-Tata, 2012). The choice of waste management practices often depends on the type of waste, the local infrastructure, financial resources, and societal attitudes towards waste. However, it is clear that effective waste management requires a comprehensive approach that minimizes waste generation, maximizes recovery and recycling, and ensures safe and environmentally sound disposal of residual waste (Kaza and Yao, 2018). Existing waste management strategies largely focus on municipal solid waste, which includes both plastic and non-plastic waste. Some of these strategies include landfilling, incineration, composting, and recycling. Landfills are the most common method of waste disposal worldwide, especially in developing countries. However, they can be a significant source of environmental pollution if not properly managed. Leachate from landfills can contaminate ground and surface water with heavy metals, organic pollutants, and other hazardous substances (Hamilton *et al.*, 2016).

Incineration, on the other hand, involves the combustion of waste at high temperatures. While it reduces the volume of waste and can generate energy, it can also release pollutants into the atmosphere, including heavy metals and dioxins (Tsydenova and Bengtsson, 2011). Composting and recycling offer environmentally friendly alternatives to landfilling and incineration. Composting is a biological process that decomposes organic waste into a nutrient-rich soil conditioner. It helps to reduce the amount of organic waste going to landfills and incinerators and contributes to soil fertility and carbon sequestration (Harris and Brown, 2010).

Recycling, which involves the collection and processing of waste materials into new products, is a key strategy for managing non-plastic waste. It helps to conserve resources, reduce energy consumption, and minimize waste disposal (Ghisellini *et al.*, 2016). However, the effectiveness of recycling programs can be influenced by a variety of factors, including the quality and quantity of collected materials, the availability of recycling facilities, and public participation (Zhou *et al.*, 2015).

While these strategies can help to manage non-plastic waste, it is clear that they are not sufficient to prevent its entry into water bodies. This is due, in part, to the fact that waste management practices often focus on the end-of-life stage of products, without addressing the upstream processes that generate waste in the first place. To effectively tackle the issue of non-plastic waste in water bodies, we need to transition towards a more circular approach to waste management, which aims to close the loop of product lifecycles through greater recycling and reuse, thereby reducing waste generation and resource consumption (Kirchherr *et al.*, 2017).

7.1 Gaps in Current Waste Management Practices

Despite advances in waste management technologies and strategies, there are significant gaps and shortcomings in current practices, particularly regarding non-plastic waste. Numerous studies have highlighted these gaps and called for urgent action to address them. One major gap is that many waste management systems, particularly in developing countries, need the basic infrastructure to handle the volume and diversity of waste generated (Hoornweg and Bhada-Tata, 2012). This often results in a significant portion of waste not being collected or treated properly, leading to its accumulation in the environment and entry into water bodies. For instance, (Kaza and Yao, 2018) estimate that around 40% of the world's waste is not managed properly, posing significant risks to public health and the environment. In addition to infrastructure deficiencies, there are also gaps in waste management policies and regulations. While many countries have enacted waste management laws, enforcement is often weak and penalties for non-compliance are insufficient to deter irresponsible behavior (Wilson *et al.*, 2015). Furthermore, many waste management policies focus on end-of-pipe solutions, such as disposal and treatment, rather than on reducing waste generation and promoting recycling and reuse (Ziraba *et al.*, 2016).

Another key gap is the lack of public awareness and participation in waste management. Despite the fact that waste management is a shared responsibility, many people lack knowledge about the environmental impacts of waste and how to dispose of it properly. This often leads to improper disposal practices, such as littering and illegal dumping, which contribute to the problem of waste in water bodies (Sidique *et al.*, 2010).

The effectiveness of recycling programs, a key strategy for managing non-plastic waste, is also often hampered by various factors. These include the lack of separation at source, contamination of recyclables, and lack of markets for recycled materials (Zhou *et al.*, 2015). Moreover, some types of non-plastic waste, such as glass and textiles, are more difficult to recycle than others, further complicating waste management efforts (Ghisellini *et al.*, 2016). Finally, there is a lack of research and data on non-plastic waste and its impacts on water bodies. While the issue of plastic waste has received considerable attention, non-plastic waste has been largely overlooked.

This gap in knowledge makes it difficult to fully understand the scale of the problem and to develop effective solutions (Blettler *et al.*, 2018). The challenges shown in **figure 4** underscore the need for a comprehensive and integrated approach to waste management. This approach should not only involve improving waste management infrastructure and enforcement of regulations, but also promoting waste reduction, recycling, and reuse, increasing public awareness and participation, and enhancing research and data collection on non-plasticwaste.

Fig. 4 Contemporary Challenges in Non-Plastic Waste Management Practices from ref. (Loan *et al.*, 2020) available under a Creative Commons Attribution-NonCommercial 4.0 International License, at https://creativecommons.org/licenses/by-nc/4.0/

8 Recent technologies

The conventional approaches to managing wastewater are insufficient to handle the progressively contaminated wastewater streams resulting from industrial and municipal operations. This is brought up by the rise in pollution levels and wastewater volumes. Consequently, developing cutting-edge wastewater treatment technology is receiving more attention in order to guarantee the safe release of industrial and municipal wastewater within the ecosystems.

Most of the recent technologies consist of hybrid systems, combining two or more treatment methods to ensure that the discharged water meets the required quality standards. The operational space, time, money, and energy usage can all be reduced by the hybrid systems (Lee *et al.*, 2012). The following sections describe a few of the most significant studies:

8.1 Advanced Oxidation Process (AOP)

This technique primarily depends on converting organic pollutants into CO_2 (carbon dioxide), simpler chemicals, and water by employing the hydroxyl radical in contaminated wastewater. This technique could be used in a fluidized bed reactor to improve treatment effectiveness all around (Cai *et al.*, 2021). There are two possible ways in which the AOPs can be combined with membrane technologies: one involves two independent units where the AOP is carried out either as a post-treatment or as a pre-treatment in the event of membrane corrosion. Combining the two processes in one reactor is the second approach, and this hybrid system is preferred because it requires less space for the treatment unit, is highly efficient, and is easier to operate because of the high filtrated flux that is produced with the help of electrostatic force (Hakimhashemi *et al.*, 2012; Tafti *et al.*, 2015). Because of the pollutants' electrochemical oxidation, membrane fouling issues are reduced. This results in elevated removal efficiency and performance at the same voltage, prolongs the membrane's life (Hakimhashemi *et al.*, 2012) and encourages the design's compactness [63]. As a result, the drag of the organic pollutants results in a decrease in energy consumption and an increase in mass transfer (Dudchenko *et al.*, 2014).

The AOP is a successful wastewater treatment method because of its benefits, including its high oxidation efficacy and lack of secondary contaminants. Numerous techniques, including electrochemical, ozone, sonolysis, Fenton, photolysis, and others, can carry out the advanced oxidation process as shown in **figure 5**. These techniques are often applied to the degradation of emerging contaminants that are not amenable to conventional methods of degradation. These methods also remove organic compounds and suspended solids.

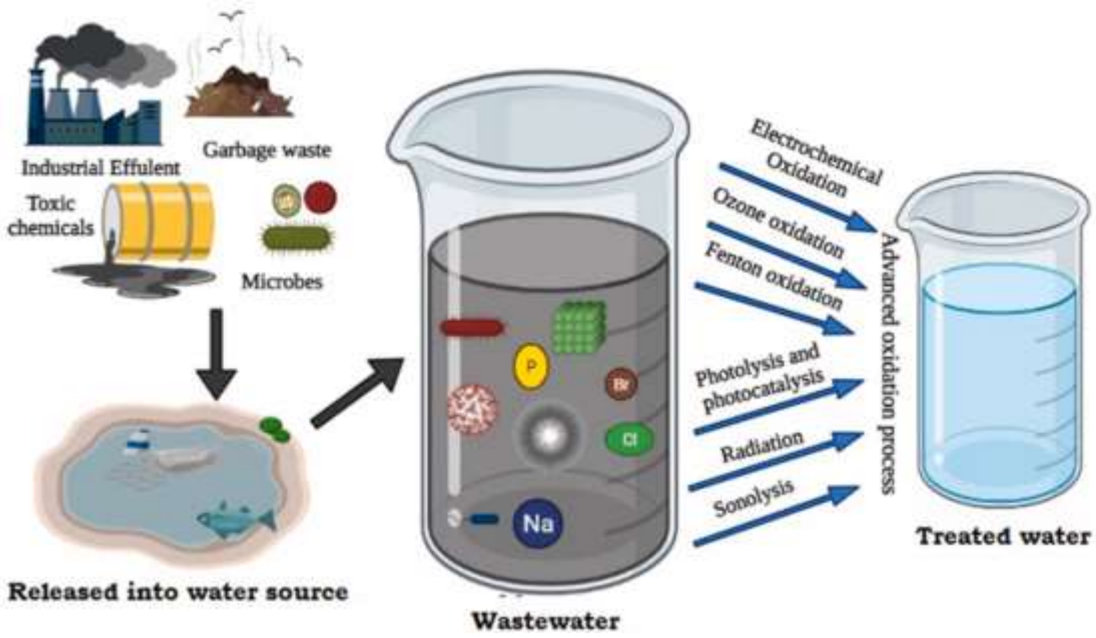


Fig. 5 Advanced oxidation processes as a potent solution for treating wastewater contaminated with diverse pollutants. Reprinted with permission from ref. (Saravanan *et al.*, 2022), Copyright 2024, with permission from Elsevier

8.2 Membrane Bioreactor

A bioreactor that uses membranes and aeration to remove organic matter is called a membrane bioreactor (MBR) (Samsami *et al.*, 2020). The capacity to handle various wastewater types, low maintenance needs, compact size, minimal sludge generation, and high efficiency are the attributes that define this hybrid system (Chang *et al.*, 2002). Furthermore, because the biocatalyst and microorganisms are retained, this approach offers excellent treatment stability. Fouling or clogging of the membrane, which necessitates frequent cleaning, remains its primary disadvantage. Because of the exerted pressure during the cleaning process, the membrane lifespan is shortened and operational costs are increased (Obaideen *et al.*, 2022). The process of breaking down complex big organic molecules into smaller ones using photocatalysts in a photocatalytic membrane reactor (PMR) yields primarily carbon dioxide and water (Karabelas *et al.*, 2018). The reactor has the ability to save energy and has features that make it simple to separate photocatalysts from treated water, prevent fouling, and reduce carbon emissions. Even so, in order to improve the water quality, the reactor still requires post-treatment (coagulation, flocculation, and sedimentation) to detach the photocatalysts from the effluent (Moslehyani *et al.*, 2018). The main variables that affect operation are the temperature, pH, wavelength and intensity of light, the characteristics of the photocatalyst, the features of the membrane, and working pressure (Zheng *et al.*, 2017). Suspended and immobilized photocatalysts are the two PMR variants (Molinari *et al.*, 2002).

8.3 Ultrasound Technique (US):

A method which breaks down various hazardous and organic contaminants into simple and biodegradable molecules by using hydro-mechanical shear forces and high oxidant chemicals such as $OH^{\bullet}$, $H^{\bullet}$, and H_2O_2 (Sangave and Pandit, 2006; Dehghani *et al.*, 2019). The disadvantages include that, when employed alone, this procedure is inefficient at treating huge volumes of wastewater with highly variable compositions due to its high capital and operating expenses. The US technique has been coupled with additional procedures such enhanced oxidative process, nanotechnology, membrane treatment, and adsorption in order to get around these challenges and reduce cost and energy need (Hilares *et al.*, 2021).

8.4 Hydrodynamic Cavitation Technology

Hydrodynamic cavitation (HC) technology relies on the formation of microbubbles, which cause a reduction in pressure and a rise in fluid velocity. The process of cavities collapsing results in active regions that possess sufficient energy to split water molecules into potent oxidative radicals and provide a significant mechanical shear force that can break down contaminants (Suslick *et al.*, 1997; Kumar and Pandit, 1999). With all of these benefits, complex compounds are more biodegradable and the treatment is simpler than with the US method (Padoley *et al.*, 2012; Gogate *et al.*, 2020). By applying the HC approach with a venturi tube operating at 13 bars for 50 minutes; it was possible to raise the biodegradability index of contaminated wastewater by nearly 60%. Further evidence of the cavitation impact was the 32, 31, and 48% decreases in chemical oxygen demand (COD), total organic carbon (TOC), and color (Padoley *et al.*, 2012). The benefits of the hydrogen bonding process include a rise in biological oxidation (Gogate *et al.*, 2020), a decrease in COD levels, the dissolution of intricate macromolecules into smaller ones, and an increase in the solubility of organic materials.

8.5 Advanced Green Technologies (AGTs)

AGTs rely on safe chemical processes and hygienic energy sources, along with environmental monitoring to decrease the adverse effects of human activity. The primary goal of green technology is to produce luxury goods without sacrificing the sustainability of the environment. Filtration is one of these technologies; it consists of an earthworm-cultivated biofilter that facilitates the collapse of organic materials into compost, which can be utilized as fertilizer. The process comprises the raw wastewater passing through the activated layer and turning the organic matter into vermicompost enhanced with humus. After that, the wastewater is passed through filter media, which has three functions: it clarifies the wastewater, nurtures the microorganisms, and collects the suspended and dissolved materials. Its advantages include the ability to be combined with other technologies, the ability to treat wastewater from hospitals, industries, and municipalities, and the fact that earthworms' burrowing motion improves aeration and prevents clogging of the biofilter (Haidri *et al.*, 2023). The overall mechanism of vermifilteration is depicted in **figure 6.**

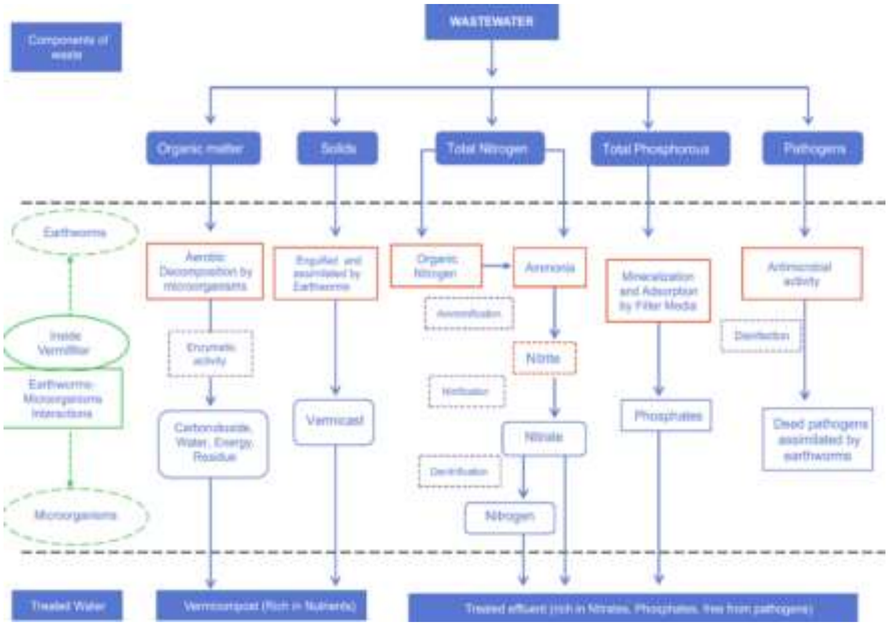


Fig. 6 Treatment of wastewater through vermifiltration technology relies on specific mechanisms to purify the water effectively from ref. (Arora and Saraswat, 2021) available under a an open access Creative Commons CC-BY license, at https://creativecommons.org/licenses/by/4.0/

Vermifilteration is seen as an eco-friendly technology from the perspective of environmental politics (Arora and Saraswat, 2021). Research on vermifiltration revealed clearance rates of 99.9, 96.9%, and 99.3% for bacteria, Salmonella, and E. coli, respectively (Arora and Kazmi, 2015). A total suspended solids (TSS) clearance of 98.4%, 91.3, and COD, as well as BOD_5, were attained, respectively (Lourenço and Nunes, 2017). More procedures have recently been added to the vermin filters to increase overall efficiency (Rajpal *et al.*, 2014). These bioreactors were cultivated with plants like Cyprus rotund us (Tomar and Suthar, 2011), Canna indica (Samal *et al.*, 2017), and Carex frankii (Singh *et al.*, 2021) to enhance the overall efficiency of the system. Ultimately, the vermin filter's cleaned wastewater might fulfill the requirements needed for irrigation and farming (Singh *et al.*, 2021). As an example, if a membrane-based treatment system is coupled with an electrochemical approach, a conductive membrane should be put in place. Nevertheless, the operating characteristics of the hybrid systems indicated above need to be tuned.

Synthetic wastewater treatment (one or more contaminants) is the main subject of most investigations. Prospective investigations ought to examine the handling of actual wastewater to assess the treatment process's overall efficacy (Malik *et al.*, 2015) . International efforts should ensure the veracity of these data, despite the difficulty of assessing the water quality data. They should also link upcoming policies with the reporting capabilities that are in place now. The indicators for wastewater treatment that have been produced are already being utilized to establish policy, identify gaps, and specify future measurement needs.

Despite global efforts to provide access to clean drinking water and sanitary sanitation, millions of people still do not have these basic necessities, as stated in UN General Assembly resolution 64/292. It is strongly advised to expand the parameters used in well-being assessments (Malik *et al.*, 2015). However, in order to meet the SDGs, the green chemistry principles, and the circular economy, there are certain obstacles to the new water treatment technologies. One of the primary obstacles to the widespread adoption of hybrid systems is the absence of global or national plans for extending their uses. Efficient scaling would be facilitated by feasibility studies and simulation modeling. The regulation of pH is an additional obstacle to the general use of modern technology. There is much work to be done in this field of inquiry.

Evaluating the function of the agents, chemicals, adsorbents, catalysts, and products of treatment is also important. Furthermore, consideration should be given to how wastewater treatment affects people, land, air, and water. A crucial component of the circular economy of the resources used in the water treatment practice is regeneration, recycling, and reuse. One of the main challenges facing the therapeutic processes is their slow kinetics. Scholars' ought to investigate novel and substitute agents. The chemicals employed in water treatment, however, are still very much outside the purview of green chemistry. Research on industrial, freshwater, marine, and agricultural wastes, as well as related materials, should be prioritized in order to lessen the adverse impact on the environment. Due to the energy required for processing or activation, as well as the chemicals and treatment agents involved, some of the more contemporary hybrid systems are pricey. Given that they are thought to be low-cost therapeutic methods, biological processes may be significant in this situation.

9 Sustainable Development Goals (SDGs)

Public authorities, including governments, must give careful consideration to a multitude of issues and concerns that exist in society. The necessity to prioritize sustainable development has grown important due to the acceleration of industrialization and urbanization in recent years. Development that occurs without adversely influencing or harming society might be seen as sustainable development. Stated differently, the understanding is that it entails fulfilling current wants at the expense of future generations' capacity to satisfy their own needs (Capodaglio *et al.*, 2017). Many difficulties and problems, counting poverty, inequality, climate alteration, environmental deprivation, and justice issues, have been faced by societies throughout the world. In this sense, the Sustainable Development Goals (SDGs) might be considered the road map for achieving greater sustainability and a better future for everybody. An in-depth examination of the specific environment and society is necessary in order to create more effective SDGs. A different approach to sustainable development may be taken in each nation or city due to the exposure to different concerns(Malik *et al.*, 2015).

The Sustainable Development Goals (SDGs) can be understood as the worldwide objectives for impartial and sustainable health at all levels. Reducing poverty, preserving and protecting the environment, and ensuring that people live in wealth and peace are some of the larger goals and approaches of sustainable development. Sustainable development pays close attention to both the present and the future. A strategy and philosophy known as "sustainable development" persuades organizations and people to take actions that benefit communities and societies as a whole (Hák *et al.*, 2016). In addition to paying attention to environmental balance and economic growth, a commitment to social progress is necessary in order to lean towards sustainable development. Initiating fundraising efforts, encouraging volunteerism, empowering change-makers, and many other initiatives are equally essential to achieving the SDGs (Stafford-Smith *et al.*, 2017).

The United Nations General Assembly set the Sustainable Development Goals (SDGs) in 2015 as show in **figure 7**. In order to achieve a better future for everybody, a plan consisting of 17 interconnected goals was created. (Stafford-Smith *et al.*, 2017). The United Nations Resolution recognized as the 2030 Agenda incorporates the SDGs. The completion of these specific goals is anticipated by 2030, and they are carefully considered and assessed to enhance the related outcomes. For each goal, the specific resolution focuses on and specifies precise targets as well as indicators that are used to gauge each target's success. Some of the Sustainable Development Goals (SDGs) have no end date, even though the majority are intended to be completed between 2020 and 2030. Many methods and technologies that help track goals' progress have been presented in order to ensure monitoring (Costanza *et al.*, 2016). The majority of nations continue to face numerous obstacles, serious obstacles, or enormous obstacles in reaching the SDG targets, according to the most recent data from the UN SDGs dashboard.

Fig. 7 UN graphic representing the 17 Sustainable Development Goals

9.1 Wastewater Contribution into SDGs:

One of the most important and crucial resources for every development endeavor is water. Water resources are becoming scarcer and contaminated due to urbanization, industrialization, and population growth. Certain elements of the naturally occurring human-caused climate change, like variations in rainfall patterns, pose a threat to exacerbate the effects even further. Water scarcity has grown to be a serious problem worldwide, which has ultimately resulted in issues of environmental, human, and economic insecurity **(Malik *et al.*, 2015)**. Wastewater is currently seen as a new supply of clean water for both potable and non-potable uses, despite its lack of importance or utility until recently. Water that would otherwise be used for industrial processes, washing, irrigation, and other applications is now fit for human consumption thanks to the filtration and treatment of wastewater.

Reclaimed wastewater is being utilized for a variety of applications and has the potential to assist society in a number of ways (Malik *et al.*, 2015). Wastewater has been found to be quite beneficial, but further research into its application could increase the advantages even further. Societies have benefited much from the process of turning wastewater into recycled water on numerous levels. Numerous parties have expressed interest in investigating future approaches to identify wastewater utilization (Henriques and Catarino, 2017). Wastewater can serve many functions in the context of sustainable development, including improved sanitation and the creation of clean drinking water to help achieve the Sustainable Development Goals. Improvements in this area are necessary to enhance the associated outcomes, since improper management of wastewater could have a number of negative effects on society. Aiming to "ensure availability and sustainable management of water and sanitation for all," SDG 6 of the 17 Sustainable Development Goals is specifically connected to wastewater treatment in water. Global benefits to humans would result greatly from achieving this aim, or even trying to partially achieve it.

Clean water is extremely important for promoting environmental conservation, socioeconomic growth, better living standards, and public health. Nevertheless, trying to utilise wastewater and optimising its utilisation could be considered extremely important (Kurian, 2017). In order to improve water quality, less wastewater will be left untreated and safe reuse and recycling will be promoted internationally. This is the sixth aim of sustainable development, which is related to clean water and sanitation. This will increase the amount of clean water that is accessible for personal use and result in significant advancements in wastewater management and sanitation. Since clean water is a scarce resource, improper collection, treatment, reuse, and disposal of wastewater will prevent clean water from ever being available. Every nation, no matter how big or little, needs to recycle wastewater and use all available resources to make the greatest use of it (Zhang *et al.*, 2016).

9.2 Planned Indicators to enhance wastewater facilities aligned with the SDGs

The plants for treating wastewater affects the SDGs in a way that is both beneficial and detrimental. When the harmful effects of these were evaluated, It was discovered that the concentrations of different heavy metals were within acceptable thresholds. However, studies also found greater concentrations of pesticides like benzene hexachloride (BHC) and *Dichlorodiphenyltrichloroethane* (DDT), as well as heavy metals in the water that these plants have treated, because the treated water was used for irrigation for a longer period of time (Karri *et al.*, 2021). Both humans and livestock eat the meals grains and veggies. Thus, while designing any waste management plan, irrigation using treated effluent needs to receive top priority.

An additional evaluation of the hazards associated with disinfection byproducts, primarily trihalomethanes (THMs), haloacetic acids (HAAs), and chlorate released from wastewater treatment plants (WWTPs) through the use of individual or combined disinfection processes, revealed that inactivation decreased the stability of THM4 and HAA9, but left chlorate unchanged following the process. However, when the same WWTPs switched to using peracetic acid as disinfectants, the amounts of disinfection byproducts were totally reduced (Albolafio *et al.*, 2022). The treated water should be effectively treated and not be used in the long run in order to reduce these harmful effects of WWTPs. However, a set of indicators—which are displayed in Table 1—were suggested in order to lessen the detrimental effect. The indicators that were suggested were created after a thorough examination of various literature sources (Dilekli and Cazcarro, 2019).

Table 1. Enhancing SDG Contributions through Proposed Indicators in Wastewater Treatment Facilities

SDGs	**Indicators**
Goal 1. Eradication Of poverty	1. Employees' average salary 2. Total tax contributions 3. Conducted employee training sessions 4. Number of workers employed
Goal 2. Ending hunger completely	5. Type of land usage. 6. Policy on disaster risk management. 7. Total recycling of nutrients, organic matter,

	and carbon.
Goal 3. Good health and wellbeing	8. Number of workplace accidents. 9. Implementation of dust control measures. 10. Total healthcare profit provided to employees. 11. Assessment of human toxicity potential, PM (particulate matter), and photochemical ozone creation potential.
Goal 4. Quality education	12. Accessibility of skill judgment programs for employees. 13. Regular training programs per employee. 14. Elimination of child labor.
Goal 5. Gender equality	15. Proportion of female recruitment and employment. 16. Wage distribution to women. 17. Representation of women in leadership positions.
Goal 6. Clean water and sanitation	18. Management of water pollution, reduction of water usage, and implementation of circular water strategies. 19. Utilization of water resources. 20. Usage of non-potable water. 21. Overall decrease in water consumption. 22. Reduction in water footprint. 23. Assessment of potential freshwater aquatic ecotoxicity and eutrophication.
Goal 7. Affordable and clean energy	24. Completion of energy balance assessment 25. Extent of energy distribution
Goal 8. Decent work and economic growth	26. Allocation towards research and development of clean technology. 27. Procurement of goods from local communities. 28. Percentage of temporary employee housing provided. 29. Job creation initiatives
Goal 9. Industry, innovation, and infrastructure	30. Undertook assessments of social, economic, and environmental impacts. 31. Implementation of circular business

	principles. 32. Monitoring and reporting on climate impact. 33. Total value contributed.
Goal 10. Reduced inequalities	34. Ratio of training programs catering to marginalized populations. 35. Overall wage gaps among various employee groups. 36. Measure of diversity and inclusivity.
Goal 11. Sustainable cities and communities	37. Implementation of sustainable resource management tactics. 38. Involvement in microgrid initiatives. 39. Total waste generation.
Goal 12. Responsible consumption and production	40. Tracking various forms of short and long-term pollution, including greenhouse gases, methane, and water contaminants. 41. Total resources and materials needed. 42. Total waste processed. 43. Potential for recycling materials such as phosphorus and nitrogen.
Goal 13. Climate action	44. Documentation of all pollution types. 45. Facility's geographical location.
Goal 14. Life below water	46. Monitoring and documenting all waterborne pollution. 47. Measuring marine ecotoxicity levels.
Goal 15. Life on land	48. Assessing the impact on biodiversity. 49. Efficiency in methane production.
Goal 16. Peace, justice, and strong institution	50. Implementation of anti-bribery protocols. 51. Engagement with stakeholders. 52. Adherence to project directives and transparency in information dissemination. 53. Total environmental violations recorded.
Goal 17. Partnerships for the goals	54. Integration of SDGs into business strategies. 55. Partnerships with various agencies for collaboration.

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9.3 Relation of Wastewater with Each SDG

The goal of SDG 6 (Clean Water and Sanitation) is to guarantee that, by 2030, everyone has access to and can sustainably manage water and sanitation. In the sections that follow, the relationship between wastewater management and other SDG targets is covered in more detail. The relationship between SDG 6 and other SDGs is depicted in **Figure 8**.

Fig. 8 The correlation between SDG 6 and other Sustainable Development Goals (SDGs) from ref. (Obaideen *et al.*, 2022), available under an open access Creative Commons CC-BY license, at https://creativecommons.org/licenses/by/4.0/

9.3.1 SDG 1: No Poverty

Poverty and water could be seen as related as, among other things, water is necessary for food production, health maintenance, employment, home construction, education, and many other activities. The likelihood of escaping the cycle of poverty may be extremely low if there is a water shortage. Water is necessary for a variety of human requirements as well as the demands of society at large. Nearly every institution in society, including offices, colleges, and schools, depends on water to function (Sims and Kasprzyk-Hordern, 2020). Society might also be incapable of guiding itself toward success and advancement. All such institutions operational effectiveness will decline, which will ultimately lead to an increase in societal poverty. A civilization or nation must have favorable conditions for overall operation and be functioning at a sufficient level in order to advance.

As water is the primary resource for producing food, farming and agriculture also depend on it. Farming communities would eventually suffer from worse living circumstances if farmers are unable to grow crops or perform related tasks due to a lack of water (Hussain *et al.*, 2024). Because enhanced infrastructure can only be achieved with abundant water resources, a society's development is likewise reliant on water availability (Shomar and Dare, 2015). In many aspects of human activity, water is an essential component. Continually available clean water is essential for any community to thrive and prosper. One idea that may help nations and communities satisfy the requirement for water availability to complete the necessary duties is wastewater reclamation.

Stakeholders are participating in processes that could use water in a variety of ways as a result of advancements being achieved in wastewater recovery and reuse (Hernández-Sancho *et al.*, 2015). Wastewater treatment facilities provide employment chances by hiring individuals, which can contribute to a reduction in the number of jobless workers (Renner, 2017). Additionally, recent developments in the treatment of wastewater, including urea fuel cells (Abdelkareem *et al.*, 2020; Sayed *et al.*, 2021), systems utilizing bio-electrochemistry that may treat wastewater and desalinate water at the same time (Tawalbeh *et al.*, 2020), energy "electricity" production (Sayed and Abdelkareem, 2017), or chemical production (Kadier *et al.*, 2020). These techniques will gradually lower the price of fresh water, boosting society's economy. Furthermore, the wastewater treatment facility has the potential to generate fertilizer of superior quality at a reduced cost, particularly for smallholder farmers (Hukari *et al.*, 2016). As a result, both their revenue and net profit will rise (Suranjan Priyanath *et al.*, 2018).

9.3.2 SDG 2: Zero Hunger

It is now essential and crucial to move forward with global sustainable development between 2015 and 2030. Clean water must be accessible in order to ensure the development of a robust food system and wholesome meals. Ensuring that people have access to clean drinking water is essential for maintaining a healthy diet worldwide. Many people around the world suffer from a lack of access to clean water, which has a negative effect on their health. It is crucial for humans to receive enough clean water to drink each day for a balanced diet (Jaramillo and Restrepo, 2017). Conversely, irrigation may be considered a crucial factor in relation to food, hunger, and nutrition. Wastewater has been shown to be a major source of the water required for effective irrigation. The direct correlation between water nutrition and other factors has long been recognized. Water must be available in sufficient quantities for the processes involved in food production. A lack of water or stagnant water is typically the reason why people are unable to cultivate enough food for sustenance. In this context, wastewater might be viewed as a crucial component since it allows the water to be filtered and used again for the growth of food (Vergine *et al.*, 2017). In addition to growing food for their families, the impoverished might use the water for a variety of other uses if there was sufficient availability for crops (Delanka-Pedige *et al.*, 2021).

Water that is sufficient to satiate hunger and other basic requirements may be made available through wastewater reclamation. Water that is clean is essential for agriculture, and wastewater management can help meet this requirement. The repurposing and recycling of wastewater has grown more successful as a result of technological breakthroughs and improvements, leading to the achieved results more efficiently. One further global concern that needs the responsible authorities' immediate attention is undernourishment, which is particularly dangerous for people who live in slums and other underdeveloped places (Valipour and Singh, 2016). Chronic undernourishment can be synonymous with hunger, and it occurs when there is insufficient food available to each person. People become hungrier since there is less room for food to grow and produce as a result of the limited water supply in some places.

Wastewater may boost and facilitate crop development if it is properly handled and used in an optimal way through reuse and recycling. After that, hunger could be effectively addressed and the goal of eradicating hunger could be reached in line with (Behera *et al.*, 2019). A ton of generated sludge was calculated to produce roughly 14 kg of N, 6.75 kilogram of P, and 4.25 kg of K. Additionally, the greater levels of potassium (K), nitrogen (N), and phosphorous (P) in the treated wastewater delivers good result on the crop production in the areas getting it (Ullah *et al.*, 2024). With phosphorus-based fertilizers becoming less available and endangering food security, there is growing interest in recovering the vital macronutrient from wastewater (Zohar and Forano, 2021).

9.3.3 SDG 3: Good Health and Wellbeing

The presence of fungi, bacteria, viruses, and parasites in raw wastewater can result in illnesses of the lungs, intestines, and other organs (Moustafa, 2017). The bacterium it spreads can also result in fever, diarrhea, cramps, and even headaches. Wastewater management is extremely important since it can lead to a number of health problems (Zhu *et al.*, 2018). Present-day WWTPs considerably reduce the risk of possible illnesses. By treating wastewater, disease-causing bacteria and other hazardous organisms that are detrimental to human health are eradicated (McCall *et al.*, 2020). Despite the fact that wastewater is associated with these dangers and potential adversities, not enough research has been done in this area, and as a result, people have been suffering a number of challenges (Salgot and Folch, 2018).

Eliminating wastewater's smell is another major advantage of WWTPs. The use of modern technologies and nanotechnology has greatly reduced the scents produced by one of the side effects of WWTPs, however this effect still exists (Fan *et al.*, 2020). Increased sewage volume due to population growth has ultimately resulted in an increase in hazardous chemicals and other pollutants that are harmful to human health. Many deaths have been caused by issues with sewage and wastewater treatment over the years, making them essential for maintaining human health. Untreated wastewater has caused some people to become ill, but some people have even died as a result of it (Shakir *et al.*, 2017). Urban and rural communities have experienced different impacts from wastewater in terms of how it affects human health. Because wastewater in rural regions is not well managed or treated, there is a higher risk of disease transmission through it. But, in metropolitan areas, there is comparatively more water management and some degree of obstacle control. Wastewater treatment has the potential to improve people's health and well-being, given the correlation between the two. Advancements in this domain may enable people worldwide to maintain optimal health and circumvent associated hardships (Delanka-Pedige *et al.*, 2021).

9.3.4 SDG 4: Quality Education

The situation is becoming worse every day even though there is enough fresh water on the earth but people have little access to it. The deficient infrastructure in managing and regulating the water supply and the weak economy are the causes of this. Given that most people in developing nations live in rural regions and depend on agriculture for a living, it is crucial to establish chances for individuals to pursue higher education and a variety of occupational skills in order to assist them overcome these challenges and meet the goals of the Sustainable Development Goals (SDGs) According to Cooper et al. (Cooper *et al.*, 2015) , Water supplies for farmers are being reduced as a result of the wastewater issue, and fresh water supplies are becoming more contaminated as a result. Either agricultural items are destroyed as a result, or their quality is compromised. Due to lower family income, children in rural areas are compelled to work in cities rather than attend school, which increases child labor. All of these factors have a negative impact on rural families' income, which subsequently causes poverty.

9.3.5 SDG 5: Gender Equality

Since water is a basic human need, it has also affected women's lives as much as men's. But compared to men, women face more difficulties as a result of different wastewater policies. Women are impacted by inadequate wastewater treatment more than males are when it comes to wastewater. Women are more likely to be exposed to hazardous wastewater when working at home or on farms because the majority of them are domestic workers. The majority of women perform unpaid or inadequately compensated labor in a variety of fields, particularly domestic and agricultural work is another terrible aspect of our society. According to Herrera, Their lack of resources also puts them at risk of drinking contaminated or untreated water on a regular basis.

9.3.6 SDG 6: Clean Water and Sanitation

Improved availability of pure water is mostly dependent on wastewater treatment. Because of the numerous health risks associated with sewage and wastewater, people nowadays require access to clean water. Clean water, aside from personal hardships, is essential to civilizations and overall growth prospects. Water could be seen as a key component of the social evolution that is occurring today. It is hard to move in the direction of development or advancement without water, thus it is now essential to make sure that there is an adequate supply of clean water available. With the removal of dangerous bacteria, viruses, and parasites, wastewater systems now serve a critical role in cleanliness and disease prevention (Salgot and Folch, 2018). The development of technology that could provide clean recycled water has been the focus and inclination of societies and governments. Resources are being used in this area in order to maximize the benefits that come with wastewater management, which is mostly dependent on clean water and sanitation. Because there are a lot of problems connected with wastewater, it is imperative that appropriate wastewater management be implemented (Angelakis and Zheng, 2015).

The atmosphere that is formed in society is impacted by the poor and inadequate treatment facilities that are found in many different places (Dickin *et al.*, 2020) . In terms of sewage and sanitation, government action is deemed to be extremely necessary. Government actions and laws could have a direct impact on wastewater management, which could ultimately have an impact on society as a whole. One may argue that wastewater and sanitation are related to one another because sanitation reduces the hazards and harms that wastewater may pose to people. Effective wastewater treatment is essential to having clean water. To minimize any potential harm to groundwater quality, a clean and safe method must be ensured (Lu *et al.*, 2015). The availability of clean water may rise as a result of these advancements, which would ultimately benefit society's citizens (Winkler *et al.*, 2017).

9.3.7 SDG 7: Affordable and Clean Energy

Many places across the world need to make new investments and adopt new regulations in order to achieve efficient energy use for water treatment. However, the creation of renewable energy, like hydropower, which is regarded as one of the world's leading sources of electricity, is heavily dependent on clean water. The use of renewable energy in the global sectors has climbed to 1.5% compared to the first quarter of 2019, according to reports from the first quarter of 2020 (Kholod *et al.*, 2015). According to the reports, the total amount of renewable energy used worldwide is expected to rise by almost 1% in 2020. Numerous organic compounds found in wastewater have the potential to be converted into energy. Wastewater's internal energy is estimated to be between 6.37 and 7.6 kJ/L (1.75 and 2.11 kWh/m3 (Heidrich *et al.*, 2011). Typically, the sludge from various wastewaters is hydrothermally treated to reduce complex organic molecules into smaller ones that are easily utilized in the anaerobic digester to produce biogas. After pre-treatment, the generated biogas can be utilized immediately in combustion operations (Yilmaz and Gumus, 2017) or as electricity-producing fuel cells (Abdelkareem *et al.*, 2019).

Another technique that can be used to raise the biogas's energy density is methanation (Abdelkareem *et al.*, 2019; Witte *et al.*, 2019). The utilities are now able to provide communities with affordable energy because the cost of generating power has decreased due to the utilization of wastewater resources. For example, the San Luis Potosi power plant in Mexico uses treated wastewater rather than groundwater, which lowers expenses by 33% and results in savings of around US$18 million over the course of the power service's six-year period. Additionally, the Cusco wastewater treatment plant saves roughly US$230,000 annually on the transportation of biosolids.

9.3.8 SDG 8: Economic Growth and Decent Work

Significant obstacles to finding acceptable work prospects because of low investment and a lack of development initiatives brought on by uneven and sluggish progress around the globe, particularly in developing and impoverished nations. Every nation's authority must create policies for societies to have sustainable economic growth, giving people access to well-paying jobs that fuel economic expansion and advance the nation forward. In fact, ensuring sustainable growth for everybody depends on effective wastewater management. Encouraging various investors in the wastewater management plant and growing treatment plants and systems in the health and other water-dependent sectors might result in the creation of long-term job possibilities(Israilova *et al.*, 2023). Numerous professions requiring a wide range of abilities, expertise, and experiences will result from this.

The government can take the lead in providing quality employment opportunities in the areas of sanitation, health, and well-being by leveraging diverse data related to wastewater and employment. By analyzing this information, they can enhance job quality within the wastewater sector. Expanding the global network of wastewater treatment plants could potentially generate numerous jobs, catering to a variety of skill sets and expertise levels. (Timmis *et al.*, 2017). Because of the increased foreign money, the nation's economy will grow and, to some extent—especially in developing nations—the issue of unemployment will be resolved. This will result in a rise in the GDP as shown in **figure 9**. For instance, a Chinese province-by-province data analysis indicates a correlation between GDP and good wastewater treatment efficiency (Shi *et al.*, 2021).

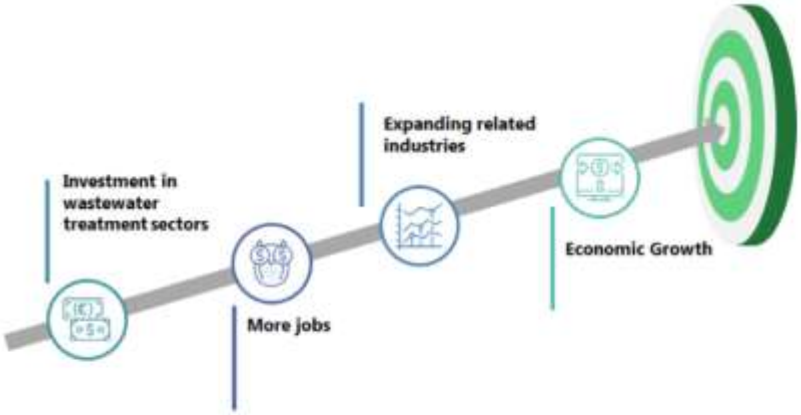

Fig. 9 Treatment of wastewater contributes to SDG 8: growth in the economy and decent work from ref. (Obaideen *et al.*, 2022), available under an open access Creative Commons CC-BY license, at https://creativecommons.org/licenses/by/4.0/

Reduced water costs or recycling will also result in lower overall operating costs for industrial facilities, as most of them rely on water for their operations (Abu-Ghunmi *et al.*, 2016). The wastewater treatment facility can also recycle components, such as crude proteins that can be recovered using ultrafiltration from poultry wastewater, resulting in a decrease in the COD of process wastewater (Avula *et al.*, 2009). The trend of valuable biomass released from wastewater containing photosynthetic bacteria (PSBs) is encouraging. This PSB seeks to ensure that technology advances across nations to offer answers to the problems they encounter about environmental and economic concerns. A range of industries, including food, chemical, agricultural, and medical treatment, as well as wastewater treatment companies, could benefit from the expansion of additional valuable resources and materials, including polysaccharides, single cell protein, polymers, Coenzyme Q10, carotenoids, and bacteriochlorin.

9.3.9 SDG 9: Industry, innovation, and infrastructure

The advancement of a nation, particularly its economy, is contingent upon its industry, infrastructure, and ability to foster technological innovation. Wastewater treatment is seeing various developments in terms of industry, infrastructure, as well as innovations in the water sector. Numerous working groups made investments in the production of various instruments and methods for novel wastewater technologies (Mao *et al.*, 2022). Aside from that, several recent advances in wastewater technologies are also occurring, including the production of chemicals, biohydrogen, wastewater treatment, and water desalination, as well as microbial fuel cells that are used for the simultaneous generation of wastewater and electricity. These developments have the potential to alter the practices and procedures related to financing and profiting from wastewater treatment. To provide solutions for the problems that different nations are facing with economic and environmental issues, this SDG attempts to guarantee technological advancement in those nations.

According to Qu et al. (Qu *et al.*, 2019), the main thing that is bad for the environment is wastewater. In order to reduce the risks that wastewater poses to the environment, it is necessary to invest in scientific research, innovation, and industry promotion. Not only will this aid the environment by reducing pollution and the ecological impact, but it will also help small-scale enterprises in the rural area by lowering water costs and creating a lot of job opportunities (Ren *et al.*, 2019) . At the end of the day, this advances the nation's economic growth. Giving the trash more value is a further advantage of wastewater treatment. Treatment of wastewater will, for instance, add value to the Greek olive oil industry's supply chain, according to a review of the sector (Valta *et al.*, 2015).For oil palm and other goods, similar experiments were carried out (Abu-Ghunmi *et al.*, 2016).

9.3.10 SDG 10: Reduced Inequality

One of the main issues facing the modern world is inequality, both between nations and among people themselves. Making sure that no one is left behind is one of the primary goals of the SDGs, which is to reduce inequality. Reducing disparities between countries can take several forms, including diminution of trade edges and disparities, relative income, etc. According to Street et al. (Street *et al.*, 2020), The objective of leaving no one behind is to give people with lower incomes the chance to gain from and engage in international trade, as well as to promote economic growth by generating investment possibilities within the nation. Nevertheless, global inequality is increasing daily, even with the UN's efforts in this area. Because less developed nations have less access to technology and infrastructure, there is a severe water problem that is affecting many countries worldwide.

Inadequate frameworks for managing and treating wastewater exacerbate the situation and lead to losses for the environment and economy in many nations. Developed and developing countries have very different access to the technologies and equipment utilized in wastewater treatment plants. People's lives are more negatively impacted in developing nations due to health and environmental problems that vary depending on the location. Research indicates that the risk of water-borne illnesses killing children is significantly higher in developing nations than in industrialized ones (Yuan *et al.*, 2017). Although treating wastewater is crucial, most developing countries' citizens cannot afford the pricey equipment and methods required. Because of this, the inhabitants in these countries, especially the impoverished, are highly susceptible to many illnesses including waterborne infections.

9.3.11 SDG 11: Sustainable Cities and Communities

The rapid expansion of urban populations and migration towards cities necessitated sustainable development across various sectors such as infrastructure and economy to support the growth of urban areas. According to El Zein et al. (ElZein *et al.*, 2016), A sustainable city accommodates and promotes commercial opportunities for its residents. Additionally, it offers them reasonably priced and secure accommodation, which improves the city's standing in terms of economic activity and the economy. A growing population will improve a variety of activities across numerous industries. For instance, the building sector will work more to provide housing for people, among other things. Resources and raw materials are necessary for these tasks. In addition to being used for home purposes, water is one of the primary resources in all these operations. Various sources claim that the demand for water worldwide is rising daily and that urban conditions are becoming increasingly dire (Capodaglio *et al.*, 2017). The authorities responsible for managing the city's water resources must prioritize urban water management.

Maintaining a sustainable environment and climate in cities greatly depends on the treatment and management of wastewater. When appropriately utilized, it can be a good and economical source of energy, water, and other consumables. This opens up a host of alternatives for treating wastewater. According to Cornejo et al. (Cornejo *et al.*, 2016), Being the center for wastewater, one of the biggest problems facing cities is managing wastewater. The massive volume of wastewater from homes and businesses is the biggest management and treatment problem for the city administrator. Determining how the city's infrastructure and materials can meet the issues associated with sewage management and treatment is consequently crucial for the administrators. On the other hand, haphazard and poorly managed approaches to resolving these problems will ruin most cities' infrastructure and lead to extremely poor living conditions. Effective wastewater management is essential for the development of a sustainable city and community as shown in **figure 10**. The city management authority can do this through implementing good governance practices and fostering cross-agency collaboration.

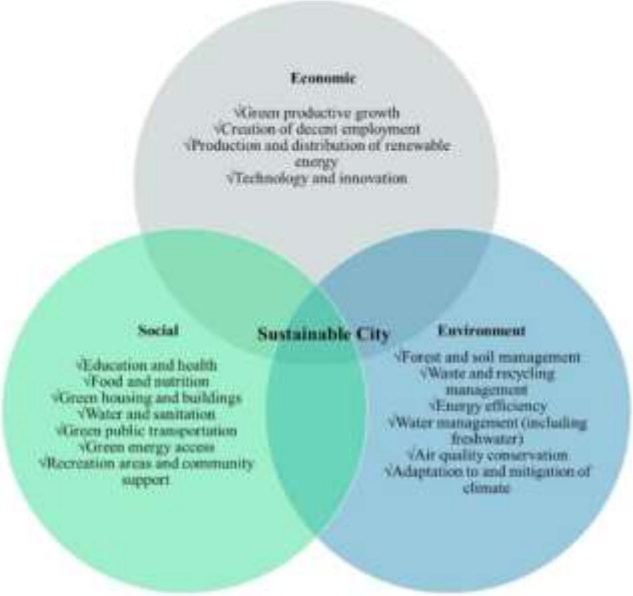

Fig. 10 Highlighting the Significance of Water Availability in Achieving Urban Sustainability from ref. (Obaideen *et al.*, 2022), available under an open access Creative Commons CC-BY license, at https://creativecommons.org/licenses/by/4.0/

9.3.12 SDG 12: Responsible Consumption and Production

The majority of natural resources that humans use are nonreversible, meaning that once they are used, they cannot be replenished. It will take time for humans to alter how they use these resources in the manufacturing of various products and consumer goods in order to achieve sustainable development and economic progress. Since water is a limited resource that is used for practically all human activity, from home to industrial, the situation is particularly dire when it comes to water (Gu *et al.*, 2018). Globally, 70% of the freshwater on Earth comes from agricultural use (Abobatta, 2018). The amount of freshwater that is available on Earth is significantly reduced due to human contamination of water sources, including the discharge of pollutants and toxic waste into streams, as well as the production of a significant amount of highly contaminated wastewater from various industries and domestic sources. Therefore, SDG 12 aims to encourage the circular economy, prolonging the products' lifespan and circulation in the economy. Treating wastewater will aid in accomplishing this goal. It will be completed by reusing the valuable materials that are extracted from the wastewater simply the water (Guerra-Rodríguez *et al.*, 2020). For example, Kurniawan et al. (Kurniawan *et al.*, 2021) demonstrate the potential uses of the macrophytes to convert wastewater into adsorbents, charcoal, fertilizer, animal feed, and biofuel.

According to Nhat et al. (Nhat *et al.*, 2018), When it comes to freshwater supply, by 2050, half of the world's population will be severely stressed. It is crucial to educate and raise public awareness in order to prevent contamination of this most essential natural resource and to prevent wasteful spending in order to eradicate all of these negative effects related to water. According to De Francisci et al. (De Francisci *et al.*, 2018), In order to minimize water waste and recycle polluted water for reuse after the necessary treatment, it is crucial to urge enterprises, factories, and other academic institutions to use water wisely. In order for regular people to have access to pure water and prevent contaminants from wasting this essential resource, industrialized nations and other non-governmental organizations (NGOs) have a duty to assist developing nations in setting up wastewater treatment plants. Additionally, this eliminates risks by preventing contamination in the environment, particularly in aquatic bodies of contamination to the environment.

9.3.13 SDG 13: Climate Action

Rapid changes in climate are closely related to wastewater. This SDG attempts to control and increase the usage of renewable energy sources in order to lessen the effects of climate change (Griggs *et al.*, 2017). A percentage of wastewater can be recycled and chemically treated to create inexpensive, environmentally friendly electricity as water is a significant source of renewable energy. Reducing the effects of climate change can be achieved by increasing the capacity of wastewater treatment, particularly in developing nations (Mara, 2013). In order to reduce the consumption of fresh and subsurface water resources, the water that has been chemically processed to eliminate pollutants and compounds can subsequently be used to generate energy. According to Dogan and Seker (Dogan and Seker, 2016), Environmental safety and health for both humans and animals are guaranteed by the advancements in the renewable energy industry, which can drastically cut pollution. To further create awareness of the additional environmental issues associated with desalination, wastewater recycling is favored over saltwater desalination (Parkinson *et al.*, 2019). Given the significance of wastewater treatment, less fresh water from rivers and lakes will be used in the future to create renewable energy sources. In addition, the treated wastewater that was released back into the environment might be used for various purposes, such as farming and cleaning.

Companies are required by the government's climate change strategy to generate more electricity from renewable resources than from conventional power plants. Because treated wastewater may be utilized in an environmentally friendly energy generation process, it can be used in compliance with climate change policies (Quaschning, 2019). If the treatment facility considered all potential greenhouse gas emissions from the facility, this will ultimately result in a reduction of the facility's overall greenhouse gas emissions (Mannina *et al.*, 2016). For example, if the renewable energy industry grows, it will contribute to a decrease in CO2 emissions from sectors that manufacture electricity and huge power plants. Businesses are now concentrating on recycling wastewater rather than discharging it into the ground or waterways. The program lessens the consequences of acid rain and climate change. Furthermore, this will lessen the acceleration of climate change, which experts believe is unpredictable, and save the ecology from contamination.

Wastewater treatment regulations attempt to reduce the amount of wastewater without treatment that contains particles of sewage, such as litter, that might damage the environment. The regulations assist in lowering the risk to marine species' health and the long-term harm to the environment. In order to preserve river flows for conservation, fishing, and other recreational purposes, efficient treatment rules and processes allow the treated wastewater to return to the environment (Gardner *et al.*, 2013). Government-developed climate change policies lead both big and small businesses to engage in environmentally sustainable growth in order to create a better world for everybody. Furthermore, the biogas industry—which helps achieve most of the SDGs, not just SDG 13—benefits greatly from the wastewater treatment process (Obaideen *et al.*, 2022).

9.3.14 SDG 14: Life below Water

Animals, plants, and other species make up the aquatic ecosystem, which is home to life below the surface of the water. There are many fish as well as reptiles in waterbodies, so it is important to protect their life and make sure that human activity doesn't negatively affect them in any way. One could argue that there is a direct correlation between life below the water and wastewater management. After being cleansed, the water that has been contaminated by human activity is discharged into rivers, where it finally joins the sea. Inadequate treatment of the water will result in the presence of chemicals and other contaminants that pose a serious threat to submerged life (Spiller *et al.*, 2015). Living things found in seas and oceans, including plants and animals, may perish if recycled wastewater is not handled properly.

Wastewater can be filtered and treated to make harmless the chemicals and other compounds that threaten marine life below the surface. Because wastewater treatment may have long-term effects on not only the plants and animals but also the human lives that are associated with it, it becomes essential for life below the surface (Thines *et al.*, 2017). Humans eat fish and other aquatic animals for food in many places of the world. The health of the creatures will be significantly impacted if wastewater continues to enter the ocean. The health problems could get much worse after humans eat these animals that have been harmed by tainted water.

9.3.15 SDG 15: Life Land

Clean water is naturally able to be stocked on healthy ground. However, as the land deteriorates, this ability disappears. For example, inadequate management of irrigation and high amounts of drainage dumped on the soil have lowered soil quality, which impacts the growth of plants and forests. Thus, rules and plans for managing and protecting land and water resources as well as minimizing wastewater spills on land must be developed. To design the proposal for the enhancement of the wastewater treatment process, an environmental impact statement (EIS) has been created (Sánchez, 2014) . Based on research findings, all wastewater treatment facilities that produce more than 10,000 PE must have an EIS. Improves to the soil, water quality, fisheries, tourism, and amenity value are made possible by the rules established to control wastewater flow. The protection of land, human, animal, and other species' lives, is facilitated by wastewater treatment. The wastewater project that best demonstrates the most innovation in terms of optimizing the physical or ecological footprint to have a significant influence on biodiversity and ecosystem is the wastewater treatment facility in Paso Robles, USA, according to the Global Water Awards (Waqas *et al.*, 2020).

9.3.16 SDG 16: Peace, Justice and Strong Institution

Water resource corruption can be significantly reduced over time by the use of good anti-corruption procedures. Organizations can analyze, avoid, lessen, and keep an eye on instances of bribery with the aid of anti-bribery management systems (Mareai *et al.*, 2020). Wastewater treatment enterprises can be protected and their integrity preserved among stakeholders thanks to the certified ISO 37001 Antibribery Management System. Aside from helping stakeholders monitor and manage the risk associated with any illicit conduct in the distribution of inexpensive hydroelectricity, the certification benefits hydropower generation and water treatment enterprises.

The certification additionally guarantees the anti-bribery practices of the distributors, suppliers, agents, and subcontractors. Ensuring that wastewater treatment and distribution adhere to human rights norms is a responsibility shared by the electricity and utility sectors (Khalaf *et al.*, 2021). The roles that various agencies in wastewater treatment and hydropower development play in defending the rights of workers, customers, and the environment vary. In this strategy, wastewater treatment represents a greater level of peace and justice, and all stakeholders, including the community itself, support this idea. Water treatment project managers have a responsibility to uphold the laws and agreements pertaining to sustainable development and growth in order to preserve peace and justice (Cohen, 2011).

9.3.17 SDG 17: Partnerships for the Goals

Water ecosystems can be protected considerably more successfully by tax policies that the government is developing to minimize the usage of fresh water and wastewater. The capacity of discharged wastewater is inversely related to the taxes set by the government and directly depends on the ecological health status of the water (Stahel, 2013). Government-approved taxes meant to correct the shortcomings in the market. The authorized levies have made a substantial contribution to lowering environmental pollution and wastewater discharge by influencing the actions of the polluting actors. Furthermore, taxes force organizations to innovate their wastewater treatment facilities, which eventually results in less deforestation and land degradation. Under the Water Act, corporations are required to pay ecotaxes, commonly referred to as environmental taxes, at all costs (Gallego Valero *et al.*, 2018).

10 Conclusion

This study, focused on the environmental impacts of non-plastic waste in water bodies, an issue that has received considerably less attention than plastic waste. The discussion of wastewater treatment's role in achieving the SDGs was intended to support the decision-makers. The study demonstrates that wastewater treatment supports each of the SDGs both directly and indirectly. SDG 1: No Poverty, achieved by raising smallholders' income, is the most closely linked SDG. SDG 2: achieving zero hunger through increased agricultural water use, SDG 3: promoting health and wellbeing through raising the standard of the water SDG 6: clean water and sanitation - by expanding access to clean water, SDG 7: wastewater-to-energy conversion for inexpensive and clean energy SDG 8: fair labor conditions and economic expansion, raising GDP by lowering the price of water, which is necessary for all forms of production, SDG 9: industry, innovation, and infrastructure: by enhancing wastewater quality, SDG 11: water circulation to improve the waste management system and create sustainable cities and communities SDG 12: responsible production and consumption: by streamlining the trash disposal process, SDG 14:Reducing wastewater discharge to achieve Life Below Waterand SDG 13: Climate Action, achieved by producing biogas. This research concludes that: 1) wastewater treatment may be crucial to reaching the SDGs; and 2) of the 17 SDGs, wastewater treatment has a direct impact on 11 of them while having an indirect impact on the other SDGs. 3. The sector continues to face numerous obstacles in implementing the SDGs and evaluating their goals from the standpoint of wastewater. It also emphasizes how SDG 6 is related to the other SDGs and how important wastewater management is to achieving all of the SDGs. Therefore, helping to monitor the risk associated with failing to achieve this aim is the primary problem in generating indicators at the global level. It is important to identify global indicators for this purpose. As a result, governments and other organizations need to be made aware of how important this goal is. The combined efforts of administrators, stakeholders, researchers, as well as engineers will promote and improve the accomplishment of SDG 6 and the other SDGs.

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