Discover Water

Research

Sustainable sewage water treatment based on natural plant coagulant: *Moringa oleifera*

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Received: 9 November 2023 / Accepted: 18 March 2024
Published online: 28 March 2024

Abstract
In response to global water scarcity and environmental degradation, one promising technique in natural plant coagulation that has gained attention in recent years is the use of *Moringa oleifera* a plant native to the Indian subcontinent. This study investigates the potential of *Moringa oleifera* as a sustainable solution for sewage water treatment. The problem of effective wastewater treatment was addressed by employing *Moringa oleifera* as a natural plant coagulant (NPC). The methodology involved the use of a jar test as a qualitative technique in coagulation and flocculation to assess the plant's effectiveness in reducing turbidity and impurities in sewage water. The physical and chemical parameters of raw and treated water were analyzed, revealing that an optimum dose of 0.4 g/1000 mL resulted in significant reductions in various water quality parameters: turbidity by 92%, COD by 88%, total solids by 96%, chloride by 75%, total hardness by 74%, and inorganic phosphorous by 68%. The specific reduction in BOD was not provided, indicating a need for further investigation. The results suggest that *Moringa oleifera* could offer significant improvements in water quality and societal health while promoting sustainability and environmental harmony. The study concludes that *Moringa oleifera* presents a promising green technique for sustainable sewage water treatment, with implications for future research focusing on the scalability of this method and its effectiveness in treating different types of wastewater.

Keywords *Moringa oleifera* · Natural plant · Coagulation · Sustainable · Sewage water treatment · Environmentally friendly

1 Introduction

As water is fundamental to all aspects of life on our planet, its purity is of utmost importance. However, if it's not properly purified, individuals may consume contaminated water, thereby significantly increasing their susceptibility to water-borne diseases [1]. In case this happens the victims will suffer a lot of pain, be uncomfortable, and, unable to work this decreases the rate of economic growth for the countries, this could cause death [2]. The target of the United Nations Agenda 2030 of Sustainable Development Goals (SDGs) is to achieve the universal and equitable right to use safe and affordable drinking water wholly [3]. However, millions of people in developing countries are still having problems with drinking contaminated water with numerous diseases [4] but it's the responsibility of governments in countries that are underdeveloped to attain the progressive technology of water use efficiency and ensure sustainable withdrawals and supply of fresh water across all areas where people they live. Chemical coagulant techniques for treating water are the majority techniques used by many industries to purify drinking water but indicated that are ineffective to cost for all

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and toxicity and make water more acidic [5]. Therefore natural plants coagulant has the potential to substitute chemical coagulants in the water treatment process, one of them is *Moringa oleifera* which was known as natural plant medicine from the early period when it operated for controlling multiple diseases later discovered that be useful for treating water but not many people know that *Moringa oleifera* has the antibacterial present in water that may help people to use safe water [6]. Amidst the numerous benefits attributed to *Moringa oleifera*, one of the critical areas of contemporary research pertains to its application in water treatment. Water scarcity and contamination are pressing global issues that pose severe threats to public health. As communities struggle with the consequences of inadequate access to clean water, innovative and sustainable solutions are imperative. In this context, the research aims to address the specific problem of water purification using *Moringa oleifera*, focusing on its coagulation properties. Coagulation is a crucial step in water treatment processes, wherein impurities and particles are agglomerated for easier removal [7]. The natural coagulant properties of *Moringa oleifera*, particularly in the form of its seeds, have shown promise in effectively clarifying water.

The primary objectives of the research are twofold: first, to investigate the effectiveness of *Moringa oleifera* as a natural coagulant in water treatment processes, and second, to optimize the conditions for wastewater treatment using *Moringa oleifera*. The study encompasses a comprehensive analysis of the physical and chemical parameters involved in the coagulation process, with a focus on reducing turbidity and impurities.

The significance of this research lies in its potential to offer a sustainable, cost-effective, and environmentally friendly solution to water treatment challenges. If proven effective, *Moringa oleifera* could serve as an accessible and locally adaptable coagulant, particularly beneficial for communities in developing regions struggling with waterborne diseases, the exploration of *Moringa oleifera*'s properties, from its historical uses to its nutritional and medicinal value, sets the stage for a focused investigation into its application in solving contemporary water treatment challenges [8]. The research aims to bridge traditional knowledge with modern scientific inquiry, offering a holistic perspective on the potential of *Moringa oleifera* in contributing to global efforts for clean and accessible water resources. Traditional water treatment methods predominantly rely on chemical coagulants, yet these approaches often prove ineffective due to cost constraints, toxicity concerns, and the tendency to acidify water [9]. This research embarks on an exploration of natural coagulants derived from plant-based materials, with a central focus on investigating the efficacy of *Moringa oleifera* in diminishing turbidity and impurities in water. Notably, the seeds of *Moringa oleifera* stand out as essential components, driving coagulation and flocculation processes to remove turbidity and impurities from water sources. In essence, this research endeavors to unravel the multifaceted potential of *Moringa oleifera*, not only as a medicinal plant but as a sustainable solution to water purification challenges. By delving into the intricacies of its coagulation and flocculation capabilities, the study seeks to contribute to the growing body of knowledge on natural, environmentally friendly alternatives for water treatment. In doing so, it aspires to pave the way for transformative approaches that prioritize both human well-being and environmental sustainability.

1.1 Botanical and nutrition of *Moringa oleifera*

Moringa oleifera, commonly known as the drumstick tree or horseradish tree, is a multipurpose plant that is widely distributed in tropical and subtropical regions of the world. It has been traditionally used for food, medicine, and as a source of water purification The origin of *Moringa oleifera* is in the Himalayan Mountains and south of India and Africa now it's planted in numerous parts of the world where the life of people suffering by consuming risky water, *Moringa oleifera* is a genus of the Moringaceae family's fast-growing tropical deciduous plant, with dense, tuberous roots, light green leaves, and abundant flowering with elongated, pendulous fruits and seeds. It is a native crop of northern India, but it is also found in southwest Asia, southwest and northwest Africa, and Madagascar. It allows soils with a pH of 4.5 to 8, with neutral or slightly acidic pH being preferable. It is a very adaptable species that live above 20 years and can reach a height range of 5 to 10 m in a short time, reaching 4 m in 6 months. The incorporation of *Moringa oleifera* will increase the nutritional value, improving the contribution of macro and micronutrients, of which proteins, fibers, vitamins, and minerals are the most important The main food products based on *Moringa oleifera* plants were found to be high in dietary fiber and low in fat, suggesting that this plant can be used in the formulation of low-calorie food products Moringa is a unique plant in that almost all of its parts, including its leaves, seeds, pods, stem, and roots, can be used for nutrition and medicinal purposes [10]. The most common medicinal use of this plant involves drying and grinding down Moringa leaves, which contain the majority of the antioxidants. *Moringa oleifera* is used to purify water for domestic use.

1.2 Statement of research hypothesis

The statement highlights some of the limitations of existing research on the use of *Moringa oleifera* seeds for wastewater treatment. It emphasizes the need for further research to determine the effectiveness of the seeds in removing contaminants from wastewater and to optimize the dosage for maximum efficiency. Additionally, the statement highlights the lack of research on the impact of *Moringa oleifera* on microbial populations in wastewater and the sustainability of the treatment method in the long term. To address these limitations, the researcher proposes conducting experimental research to test the hypothesis regarding the potential benefits and limitations of *Moringa oleifera* in sewage water treatment. The experimental research will provide valuable data on the effectiveness of *Moringa oleifera* seeds in removing contaminants from wastewater and their impact on microbial populations. The results of the study will help to determine the optimal dosage of *Moringa oleifera* for maximum efficiency and sustainability. Overall, the experimental research will provide valuable insights into the potential of *Moringa oleifera* as a sustainable and effective method for treating sewage water.

1.3 Wastewater treatment process

Wastewater treatment is a crucial process in controlling pollution globally. The process involves the collection of wastewater from various sources, such as homes, businesses, and industries. The collected wastewater is transported through sewers to treatment plants, where it undergoes a series of treatment processes [11]. There are two primary stages involved in the wastewater treatment process, the primary stage and the secondary stage. The primary stage involves the removal of large floating objects from the wastewater using a screen. The screen has openings of uniform size that retain solid particles present in the influent wastewater. After the screening, the wastewater still contains organic and inorganic matter, along with suspended solids. These suspended solids are small particles that can be removed from the wastewater in a sedimentation tank. The primary sedimentation tank is designed to remove 50–70% of suspended solids and 25–40% of BOD, although this process alone is insufficient to meet higher water quality demands. The objective of the primary treatment process by sedimentation is to remove readily settleable solids and floating material and reduce the suspended solids content. After the primary treatment stage, the partially treated wastewater is pumped into an aeration tank in the secondary stage, where it is mixed with air and sludge-containing bacteria. The mixture is allowed to remain for several hours, and the wastewater then flows into another sedimentation tank to remove excess bacteria. The principal secondary water treatment techniques used are the trickling filter and the activated sludge process. The trickling filter involves a bed of stones, which are three to six feet deep, through which sewage passes. The activated sludge process uses microorganisms to break down organic matter in the wastewater. The secondary stage of treatment removes about 85% of the organic matter in sewage. The treated wastewater is then discharged into streams or other channels of water or can be reused for domestic purposes. The tertiary treatment stage is the final stage in the process of wastewater treatment. This stage is designed to remove any remaining organic and inorganic material, suspended solids, phosphorous and nitrogen, and other contaminants that have not been removed by the primary and secondary stages. Tertiary treatment is particularly important in areas where the treated water will be discharged into sensitive ecosystems, such as rivers or lakes, or where the water will be used for agricultural or industrial purposes. There are several techniques used in tertiary treatment, including filtration, disinfection, and nutrient removal [12]. Filtration involves the use of sand or activated carbon filters to remove any remaining suspended solids or organic material. Disinfection is the process of killing any remaining bacteria, viruses, or other pathogens that may be present in the water. This can be achieved through the use of chemicals such as chlorine, or by exposure to ultraviolet light. Nutrient removal techniques, such as the use of nitrogen and phosphorous removal systems, are used to reduce the levels of these elements in the treated water.

1.4 *Moringa oleifera* in the water treatment process

Moringa oleifera can be used for primary, secondary, and tertiary water treatment processes. However, its effectiveness may vary depending on the type and concentration of impurities and contaminants present in the wastewater, as well as the specific treatment goals. For primary treatment, *Moringa oleifera* can be used during the coagulation and sedimentation stages to remove suspended solids, organic matter, and other impurities from the wastewater. In this stage, *Moringa oleifera* can help neutralize the charges on suspended particles and promote their agglomeration, making them easier to remove during sedimentation. For secondary treatment, *Moringa oleifera can* be used during the biological treatment stage to remove dissolved organic matter and nutrients from the wastewater. In this stage, *Moringa oleifera* can be used as a carbon and nutrient source for microorganisms, promoting their growth and activity, which leads to the breakdown of organic matter and the removal of nutrients from the wastewater. For tertiary treatment, *Moringa oleifera* can be used during the filtration and disinfection stages to remove remaining impurities and pathogens from the wastewater. In this stage, *Moringa oleifera* can be used as a coagulant or flocculant to enhance the removal of impurities during filtration, or as a disinfectant to kill remaining pathogens in the wastewater [13]. Overall, the use of *Moringa oleifera* in water treatment can be highly effective when used at the appropriate stages of the treatment process and can contribute to a more sustainable and eco-friendly. *Moringa oleifera* is a tropical plant with numerous medicinal and nutritional benefits, and it is effective in the purification of water. Various studies have investigated the use of *Moringa oleifera* in the purification of wastewater, and this section will review some of the related literature regarding my work, Quintero-Jaramillo et al. [14] reviewed the cultivation and use of *Moringa oleifera* and other Moringaceae species for water purification and other purposes in Sudan. The authors discussed the potential of these plants for sustainable development in Sudan, as well as the challenges and opportunities associated with their cultivation and use. A study conducted by [15] found that one of the most common forms of pollution control worldwide is wastewater treatment. Criscuoli et al. [16] reviewed the previous studies on the use of *Moringa oleifera* seeds as a natural coagulant for water treatment. They discussed the optimal dosage, pH, and temperature for the coagulation process. Alazaiza et al. [17] reviewed the potential of *Moringa oleifera* seeds as an alternative to synthetic coagulants and flocculants for water purification. The authors discussed the previous studies that have investigated the effectiveness of *Moringa oleifera* seeds for removing impurities and contaminants from water. Aho and Lagasi [18] reviewed the potential uses of *Moringa oleifera* for various purposes, including water treatment. The authors discussed the properties and uses of *Moringa oleifera*, including its nutritional and medicinal properties, as well as its potential for use in animal feed, biodiesel production, and water purification [19]. Their research concern did draw the researcher's attention to finding a sustainable domestic solution for the poor and rural society with natural coagulants (NC) are plant-derived coagulants that can be used in the coagulation–flocculation process of water and wastewater treatment. Natural coagulants such as Neem, Tulsi, Moringa, Orange Peel, Sponge Guard, vetiver, Banana Peel, and others can be used to effectively treat water and wastewater, all of the results demonstrated that *Moringa oleifera* seeds were very effective at removing impurities [20]. NPBCs are also very effective at sweeping physic-chemical parameters of water like turbidity, TSS, TDS, and coliform bacteria, as well as wastewater parameters like BOD, COD, heavy metals (chromium, lead, etc.), color, and so on. Beletini et al. [21] investigated the use of *Moringa oleifera* seeds as a coagulant for the removal of turbidity from wastewater. The results showed that *Moringa oleifera* was effective in reducing turbidity by 95%, and it was found to be more effective than alum, a commonly used chemical coagulant. Another study by Desta and Bote [22] evaluated the use of *Moringa oleifera* seeds in removing pathogens from wastewater the study found that *Moringa oleifera* seeds were effective in removing up to 99.9% of pathogens from the wastewater, making it a suitable option for the treatment of domestic wastewater. Muyibi et al. [23] investigated the use of *Moringa oleifera* seeds in the treatment of wastewater from a cassava processing plant. The results showed that *Moringa oleifera* was effective in reducing biochemical oxygen demand (BOD) and chemical oxygen demand (COD) by 81% and 75%, respectively [24]. This study investigated the effectiveness of *Moringa oleifera* seed extract in enhancing the coagulation of high organic matter waters. The researchers found that the addition of *Moringa oleifera* extract to water samples significantly improved the coagulation efficiency and reduced the levels of organic matter in the treated water. The study suggests that *Moringa oleifera*, A study conducted by Deswal et al. [25] investigated the use of *Moringa oleifera* seed powder in the treatment of wastewater. The study found that *Moringa oleifera* seed powder effectively removed heavy metals and other pollutants from wastewater, making it a viable option for the treatment of industrial wastewater. Furthermore, a study investigated the use of *Moringa oleifera* seeds in the treatment of industrial wastewater containing heavy metals. The study found that *Moringa oleifera* seeds were effective in removing up to 95% of heavy metals from the wastewater, making it a viable option for the treatment of industrial wastewater. Rasheed et al. [13] stated that the World Health Organization (WHO) reported that 2.2 million people's deaths were due to waterborne diseases in 2016. The work of point-of-use technologies for household-level water purification reduces diarrheal disease by 30–40%. de La Grange and Prasasty [26] reviewed the previous studies on the use of various waste materials, including *Moringa oleifera* seeds, as coagulants and adsorbents for water treatment. The authors discussed the challenges and opportunities associated with using these waste materials for environmental applications Another study by Abeykoon et al. [27] evaluated the use of *Moringa oleifera* seeds in removing turbidity from wastewater. The study found that *Moringa oleifera* seeds were effective in removing up to 99% of the turbidity from the wastewater, making it a suitable option for the treatment of domestic wastewater. Similarly, a study by Zarowsky et al. [28] investigated the use of *Moringa oleifera* seed powder in the treatment of industrial wastewater. The study found that *Moringa oleifera* seed powder effectively removed up to 92% of pollutants from the wastewater, making it a viable option for the treatment of industrial wastewater. Worked on water pollution by chemicals that have become a major source of concern and a priority for both society and public authorities. Described the botany of *Moringa oleifera*, which is a small, graceful, deciduous tree with sparse foliage, often resembling a leguminous species at a distance, especially when in flower, but immediately recognized when in fruit. Ribeiro et al. [29] investigated the use of *Moringa oleifera* seed powder in the treatment of industrial wastewater. The study found that *Moringa oleifera* seed powder effectively removed up to 92% of pollutants from the wastewater. Owodunni and Ismail [30] stated that water is one of the natural resources that is needed by living things to sustain and maintain health. The current water problem frequently occurs is related to the quality of water, but drinking water is a basic need of human beings and is one of the mostindispensable requirements for the sustenance of life [31]. The availability of safe drinking water is a serious issue mostly for humans living in remote areas in developing countries. To prove that powdered *Moringa oleifera* seeds are effective. The study looked into whether using 0.3 g/500 mL of Moringa's seed powder produced the best adsorption equilibrium, color, turbidity, and chemical oxygen demand (COD) was measured for wastewater's acidic and basic properties. Taiwo et al. [31] worked on how coagulants play a vital role in the treatment of raw water for both human and animal consumption. Aluminum sulfate is the most common and effective chemical coagulant for water treatment. However, chemical coagulants are cost-ineffective, toxic, not eco-friendly, and may also cause severe health issues like cancers and neurologic disorders including Alzheimer's disease. Therefore natural and greener methods of water purification are crucial for safe and effective water treatment. Have also been used in water purification regimes [32]. *Moringa oleifera* seeds contain anti-microbial properties and cationic water-soluble proteins (polyelectrolytes) that possess active coagulative properties that can remove the turbidity and heavy metals like Cu, Pb, Cr, Zn, etc. from raw water, thus can treat impure water efficiently [33]. In this study, the authors investigated the potential of *Moringa oleifera* seed extract for the removal of dyes from aqueous solutions. The results showed that *Moringa oleifera* seed extract was effective in removing different types of dyes, with a maximum removal efficiency of 98.4%. The authors also studied the kinetics, thermodynamics, and equilibrium of the dye removal process and concluded that *Moringa oleifera* seeds extract has the potential as a natural and low-cost adsorbent for the removal of dyes from aqueous solutions. In conclusion, *Moringa oleifera is* effective in the purification of wastewater, making it a viable option for the treatment of both domestic and industrial wastewater. The studies reviewed demonstrate the potential of *Moringa oleifera* as a natural and low-cost alternative to conventional wastewater treatment methods**.** The objectives of this study were to investigate the effectiveness of *Moringa oleifera* in reducing levels of turbidity and impurities in water. To determine the optimal conditions for treating wastewater using *Moringa oleifera* and analyze physical and chemical parameters. Specifying how Natural plant coagulation is cost-effective and environmentally friendly. And To determine SWOC analysis of *Moringa oleifera* for treating sewage water.

2 Methods and materials

The sample was collected from the Tiruchirappalli city corporation Vayalur Road (HT) UGD Pumping station, which receives wastewater from various areas in the Trichy urban region. Nine samples were collected from different pipe outlets that are inflow in sewage collection stations in 1000 mL bottles—Woriyur outlets, Government hospital (GH) outlets, and other pipes connected to Vayalur road. Raw water was collected before it entered the screening and grit sedimentation tank as the source of untreated water and the samples were collected on March 20, 2023, after noon 3 h: 20 min to 3 h: 50 min we have collected the samples based on the discharging time of sewage water from different places of Trichy. Therefore the samples were kept in a fridge for one night to maintain the temperature of it [34]. Based on the relevant references, it is evident that *Moringa oleifera* has been extensively studied for its potential application as a natural coagulant in sustainable sewage water treatment. The research on natural coagulants from plant-based materials has been focused on *Moringa oleifera* in this process we have followed the process of mechanisms and coagulation has been explored for the treatment of wastewater, aiming to enhance the water quality by using natural plant-based.

As indicated in Fig. 1 illustrates how the mature *Moringa oleifera* seeds were collected and cleaned by removing their outer casing and the seed coat to obtain clean seed kernels. The amount of seed required for the purification process was determined based on the sewage wastewater sample. To prepare the Moringa seed powder, the seeds were crushed using a mortar and pestle and sifted to filter out any impurities.

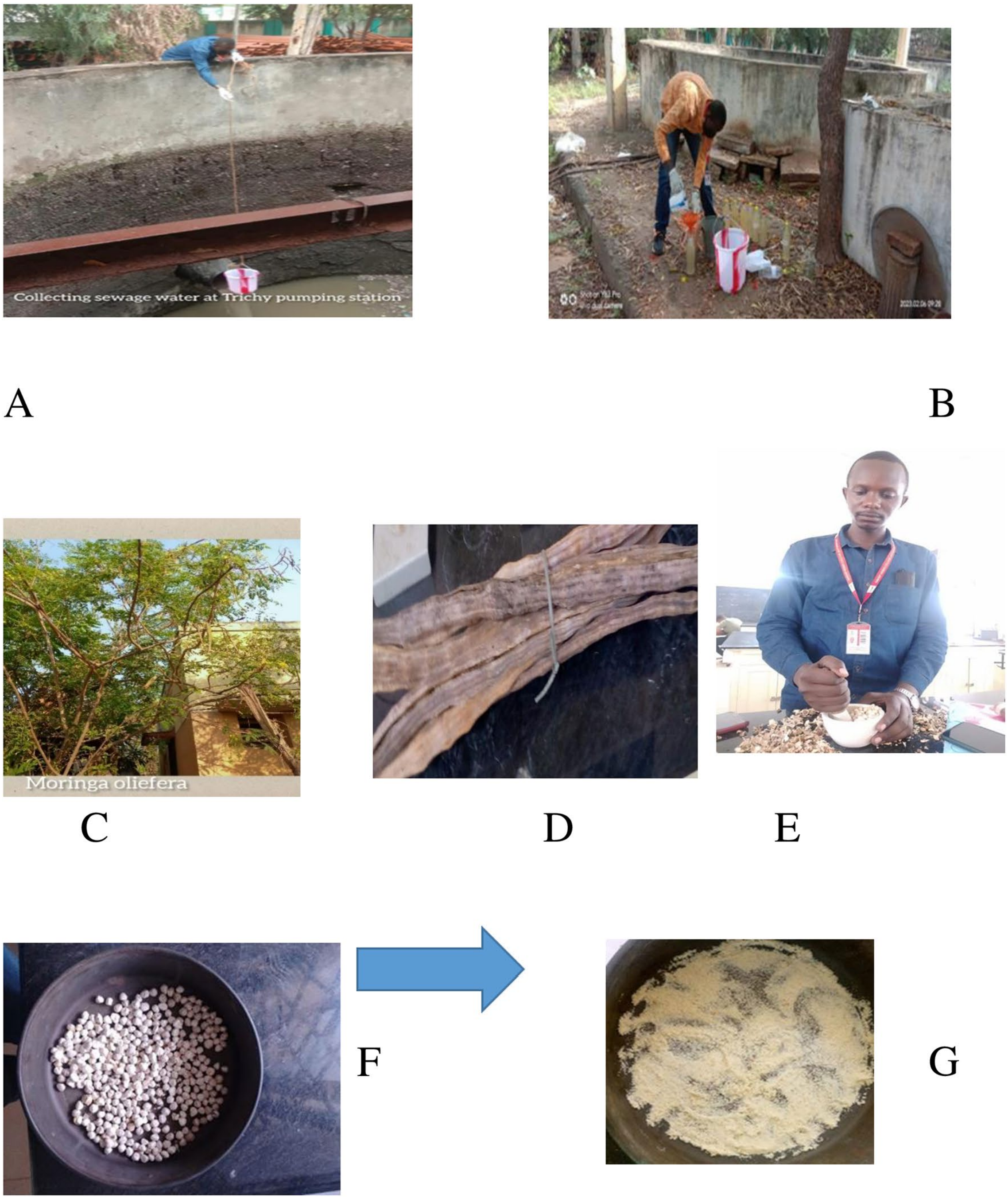


Fig. 1 **A** Indicates where samples were collected, **B** shows how the samples were filled in the sampling container, **C** its tree of Moringa oliefera, **D** shows the Moringa oleifera seeds harvested, **E** and **F** Indiacting the process of removing the outer and seed coat crushing the seeds by using a mortar and pestle, **G** fine powder used as antimicrobial and coagulation process in water treatment

2.1 Principle of *Moringa oleifera* technique for treating water

The *Moringa* technique for treating wastewater is based on the use of *Moringa oleifera* seeds as a natural coagulant and flocculant. The principle behind this technique is that the positively charged proteins in *Moringa oleifera* can bind with negatively charged particles in the wastewater, such as suspended solids, organic matter, and pathogens, and form larger particles called flocs. These flocs can then settle to the bottom of the wastewater through sedimentation or can be filtered out [35]. The Moringa technique is considered a green and sustainable alternative to chemical coagulants, which can be expensive, toxic, and can produce harmful byproducts. The *Moringa* technique can be applied to various stages of wastewater treatment, including primary, secondary, and tertiary treatment. It is effective in removing turbidity, suspended solids, organic matter, and pathogens from wastewater. The application of the *Moringa* technique is relatively simple and involves preparing a solution or powder of *Moringa oleifera* crashed manually or using the mixer and filtering to make fine powder and adding it to the wastewater. The optimal dosage of *Moringa oleifera* may vary depending on the specific wastewater characteristics and treatment goals. Overall, the *Moringa* technique for treating wastewater is a promising approach to sustainable and eco-friendly wastewater treatment, and its effectiveness and potential for widespread application are currently being studied and explored.

2.2 Experimental mechanisms and coagulation process

In our conduct evaluated evaluated the effectiveness of *Moringa oleifera* in purifying the water. We filled six beakers with 1000 mL of raw water samples and added different amounts of Moringa seed powder to each, ranging from 0.1 to 0.6 g per 1000 mL of water. We then conducted a jar test to assess the coagulant properties of *Moringa oleifera* and its ability to remove turbidity from the water. The *Moringa oleifera* powder was mixed into the water for 15 min at a speed of 120 RPM, and 5 min at 60 RPM, followed by a settling time of 20 min. After the settling period, we filtered the treated samples using membrane filtration, a highly effective method for removing smaller contaminants. We observed the changes in the water after the addition of the *Moringa oleifera* doses and found that a dose of 0.4 g effectively treated the water and removed turbidity.

Finally, we tested the physical–chemical parameters of both the treated and untreated water. This allowed us to evaluate the effectiveness of *Moringa oleifera* in treating water. The results of these tests will be used for further analysis. This experiment demonstrates the potential of *Moringa oleifera* as a natural and effective solution for water treatment. However, the optimal dosage and conditions may vary depending on the specific characteristics of the water source. In addition to our primary study, we also referred to several scientific studies on the use of *Moringa oleifera* for water treatment. This helped us understand the process and optimize the conditions for our experiment [31]. By combining our primary study, insights from scientific research, and the use of membrane filtration, we were able to conduct a thorough and effective evaluation of *Moringa oleifera*'s potential as a water treatment solution. The results of this experiment will contribute to the growing body of research on natural and sustainable methods for water purification. However, as always, the optimal conditions may vary depending on the specific characteristics of the water source.

Figure 2, demonstrates the potential of *Moringa oleifera* in the Process of coagulant and mixing the powder with the samples of water, then the Particles steeling down and comparing the sample before and after completing the coagulation process in a Jar test.

2.3 Test analysis

Table 1 elucidates the physical and chemical parameters being tested in this study to evaluate the effectiveness of Moringa treating and assessing water health safety. The important procedures are explained below:

A B

Fig. 2 **A** indicates the Raw samples of sewage water collected before introducing the treatment of moringa powder while **B** is the changes after adding the moringa dose from 0.1 g/l to 0.6 g/l with the help of a jar test as the qualitative technique of flocculation and coagulation process

Table 1 Parameters to be tested

Parameters	Methodology	Instrument	Units
Physical parameters			
pH	pH meter	pH	pH
Turbidity	Nephelometric	Turbid meter	NTU
EC (electrical conductivity)	Conductivity meter	Conductivity meter	mS/cm or μS/cm
Total solids	Gravimetric method	Analytical balance	mg/L
Total dissolved solids	Gravimetric method	Analytical balance	mg/L
Total suspended solids	Gravimetric method	Analytical balance	mg/L
Chemical parameters			
Total acidity	Titration method	Burette and indicator	mg/L or ppm
Total alkalinity	Titration method	Burette and indicator	mg/L or ppm
Total hardness	Titration method	Burette and indicator	mg/L or ppm
Calcium hardness	Titration method	Burette and indicator	mg/L or ppm
Magnesium hardness	Titration method	Burette and indicator	mg/L or ppm
Fluoride	Colorimetric method	Spectrophotometer	mg/L
Nitrite	Colorimetric method	Spectrophotometer	mg/L
Nitrate	Colorimetric method	Spectrophotometer	mg/L
Silicate	Colorimetric method	Spectrophotometer	mg/L
Inorganic phosphorus	Colorimetric method	Spectrophotometer	mg/L
Chloride	Titration method	Burette and indicator	mg/L or ppm
Potassium	Flame photometry	Flame photometer	mg/L
Sodium	Flame photometry	Flame photometer	mg/L
Sulphate	Gravimetric method	Analytical balance	mg/L
Biochemical oxygen demand (BOD)	BOD incubator	BOD incubator	mg/L
Chemical oxygen demand (COD)	Dichromate method	Spectrophotometer	mg/L
Dissolved oxygen	Winkler titration method	Burette and indicator	mg/L

pH The pH of the water samples was measured using a pH meter. The instrument was calibrated before each measurement using standard buffer solutions. The pH meter electrode was immersed directly into the water samples, and readings were taken once stabilization was achieved.

Turbidity Turbidity was determined using a Nephelometric Turbidity Meter. The instrument was calibrated with a standard turbidity solution. Water samples were poured into the turbidimeter, and turbidity readings were recorded in Nephelometric Turbidity Units (NTU).

Electrical conductivity (EC) EC was measured using a Conductivity Meter. The meter was calibrated with standard conductivity solutions. The conductivity probe was immersed in the water samples, and readings were recorded in milliSiemens per centimeter (mS/cm) or microSiemens per centimeter (μS/cm).

Total solids, total dissolved solids, total suspended solids Gravimetric methods were employed for the determination of total solids, total dissolved solids, and total suspended solids. Water samples were filtered through pre-weighed filter paper for total suspended solids, and the residues were dried and weighed. For total solids and total dissolved solids, samples were evaporated, dried, and weighed accordingly.

Chemical parameters (total acidity, total alkalinity, total hardness, calcium hardness, magnesium hardness, fluoride, nitrite, nitrate, silicate, inorganic phosphorus, chloride, potassium, sodium, sulphate, BOD, COD, and dissolved oxygen): various chemical parameters were determined using standard methods. Titration methods were employed for total acidity, total alkalinity, total hardness, calcium hardness, magnesium hardness, nitrite, nitrate, chloride, and sulfate. Colorimetric methods were used for fluoride, silicate, inorganic phosphorus, and potassium. Flame photometry was applied for the determination of sodium and potassium. BOD and COD were measured using a BOD incubator and a spectrophotometer, respectively. Dissolved oxygen was determined using the Winkler titration method.

3 Result and discussion

After treatment different parameters were analyzed according to the procedure mentioned in methodology, a summary of the Results for analysis of the physical–chemical parameters for both treated and untreated obtained were presented in the table below, Therefore for the treated water, these data presented are for the dose of 0.4 g/1000 mL of Moringa powder.

Table 2 provides the detailed result of the data after analyzing it in the laboratory for different boreholes collected in different areas however are discharged in the same station. To find the Sample Standard Deviation we used this formula; $s = n - 1 \sum (xi - \overline{x})2$, where s is the sample standard deviation, xi represents each value from the sample data set, $\overline{x}$ is the mean of the sample data set, n is the number of data points in the sample and Here the standard deviation we have calculated are for the treated water and these values we got indicate that most are closer to the standard water quality needed for various purposes so *Moringa oleifera* is the perfect option for the water treatment and provides the reality and precision of it in water quality analysis.

Source: World Health Organization (2011). Guidelines for Drinking-water Quality (4th ed.) https://www.who.int/publications/i/item/9789241548151 Bureau of Indian Standards. (2012). Indian Standard Drinking Water—Specification (IS 10500:2012). Retrieved from https://law.resource.org/pub/in/bis/S06/is.10500.2012.pdf.

3.1 Turbidity removal efficiency

The Table 3 and Graph 3 both indicate the remarkable phenomena of *Moringa oliefera* by removing the turbidity and other impurities in water and it provided in percentages (Fig. 3)

$$\% \text{ removal of turbidity} = \frac{\text{Initial Turbidity} - \text{Final turbidity} \ast 100}{\text{Initial turbidity}}.$$

3.2 Discussion

Water scarcity and environmental degradation have underscored the need for sustainable sewage water treatment methods globally. In this context, natural plant coagulation (NPC) has emerged as a promising technique, with *Moringa oleifera* gaining attention for its coagulant properties. This study aimed to investigate the effectiveness of *Moringa oleifera* in reducing turbidity and impurities in water, determine optimal treatment conditions, analyze physical and chemical parameters, and evaluate the effectiveness and environmental friendliness of natural plant coagulation.

Turbidity reduction: Turbidity, a crucial indicator of water quality, reflects the presence of suspended particles. The study successfully demonstrated the efficiency of *Moringa oleifera* in reducing turbidity levels across various sampling points. The optimal dose, determined to be 0.4 g/1000 mL, showcased remarkable turbidity reductions—Woriyur outlets: 81.1 NTU to 6.2 NTU; Vayalur road: 76.8 NTU to 10 NTU; Government hospital: 74.4 NTU to 11.4 NTU. This substantiates *Moringa oleifera*'s potential to enhance water clarity through natural coagulation.

Optimal treatment conditions: Determining optimal treatment conditions is imperative for the practical application of *Moringa oleifera* in wastewater treatment. The study's success in achieving significant turbidity reduction suggests that the selected dosage and treatment duration are effective. Fine-tuning these parameters based on specific water characteristics and regional variations could further enhance the plant's efficiency in diverse settings, contributing to sustainable and efficient treatment practices the Characterizations of this study were determined and explained in the following ways:

Physical parameters analysis: The analysis of physical parameters, including pH, electrical conductivity (EC), and total solids (TS), provided insights into the broader impact of *Moringa oleifera* treatment.

- PH: While *Moringa oleifera* treatment led to slight variations in pH, the changes were within acceptable limits. This indicates that the coagulant does not significantly alter the water's acidity or alkalinity, ensuring the treated water remains suitable for various applications.

Table 2 The physical and chemical parameters results estimated in raw and treated

Parameters	Pipe outlets	Raw sample	Treated sample	Standard deviation
The physical parameters				
pH	Woriyur outlets (S1)	7.54	7.05	0.20
	Vayalur road (2)	7.48	7.39	
	Government hospital (S3)	7.27	7.09	
Turbidity (NTU)	Woriyur outlets (S1)	81.1	6.2	2.23
	Vayalur road (2)	76.8	10	
	Government hospital (S3)	74.4	11.4	
EC (ms)	Woriyur outlets (S1)	1.855	1.702	0.08
	Vayalur road (2)	1.925	1.729	
	Government hospital (S3)	1.650	1.532	
Total solids (TS) mg/L	Woriyur outlets (S1)	1690	504	316.06
	Vayalur road (2)	956	446	
	Government hospital (S3)	1180	1152	
Total dissolved solids (mg/L)	Woriyur outlets (S1)	730	534	119.63
	Vayalur road (2)	584	532	
	Government hospital (S3)	350	280	
Total suspended solids (mg/L)	Woriyur outlets (S1)	966	30	377.29
	Vayalur road (2)	372	86	
	Government hospital (S3)	900	802	
Chemical parameters result estimated in raw and treated water				
Fluoride (mg/L)	Vayalur road (2)	0.32	0.23	0.0082
	Government hospital (S3)	0.30	0.24	
	Woriyur outlets (S1)	0.31	0.22	
Total acidity (mg/L)	Vayalur road (2)		Nil	
Total alkalinity (mg/L)	Government hospital (S3)	2.5	1.25	0.625
Total hardness (mg/L)	Woriyur outlets (S1)	185	130	47.36
	Vayalur road (2)	795	245	
	Government hospital (S3)	675	175	
Calcium hardness (mg/L)	Woriyur outlets (S1)	150	105	21.61
	Vayalur road (2)	175	155	
	Government hospital (S3)	160	145	
Magnesium hardness (mg/L)	Woriyur outlets (S1)	60.12	42.084	8.64
	Vayalur road (2)	70.14	62.12	
	Government hospital (S3)	64.128	58.1	
Chloride (mg/L)	Woriyur outlets (S1)	223.35	134	45.21
	Vayalur road (2)	220	120	
	Government hospital (S3)	200	49.63	
	Woriyur outlets (S1)	0.828	0.531	
Nitrate (mg/L)	Vayalur road (2)	0.5	0.5	0.0
Nitrite	Government hospital (S3)	–	–	
Potassium (mg/L)	Woriyur outlets (S1)	84.38	86.15	31.20
	Vayalur road (2)	11.49	14.89	
	Government hospital (S3)	13.95	14.54	
Sulphate (mg/L)	Woriyur outlets (S1)	8.0	7.5	3.12
	Vayalur road (2)	26	5	
	Government hospital (S3)	22.5	12.5	
Inorganic phosphorus (mg/L)	Woriyur outlets (S1)	1.13	1.02	0.09
	Vayalur road (2)	1.19	1.05	
	Government hospital (S3)	2.6	0.82	

Table 2 (continued)

Parameters	Pipe outlets	Raw sample	Treated sample	Standard deviation
Silicate (mg/L)	Woriyur outlets (S1)	12.4	6.6	0.73
	Vayalur road (2)	10.0	8.2	
	Government hospital (S3)	9.0	7.2	
Sodium	Woriyur outlets (S1)	141.9	131.9	14.33
	Vayalur road (2)	188.01	150	
	Government hospital (S3)	200	170.05	
Biochemical oxygen demand (mg/L)	Woriyur outlets (S1)	–	28.7	13.38
	Vayalur road (2)	–	26.8	
	Government hospital (S3)	–	56.6	
Chemical oxygen demand (mg/L)	Woriyur outlets (S1)	340	40	48.10
	Vayalur road (2)	536	144	
	Government hospital (S3)	332	44	
Dissolved oxygen (mg/L)			Nil	

Table 3 Coagulation and flocculation analysis using a jar test

Beaker designation	Dose of coagulant (g/1000 mL)	Initial turbidity	Final turbidity	Analysis of water
1	0.1	74.5	40.4	Bad
2	0.2	62.0	30.5	Fair
3	0.3	51.9	26.1	Good
4	0.4	81.1	6.2	Excellent
5	0.5	76.8	10	Very good
6	0.6	74.4	11.4	Very good

Result/optimum dose of coagulant of MO = 0.4 g/1000 mL

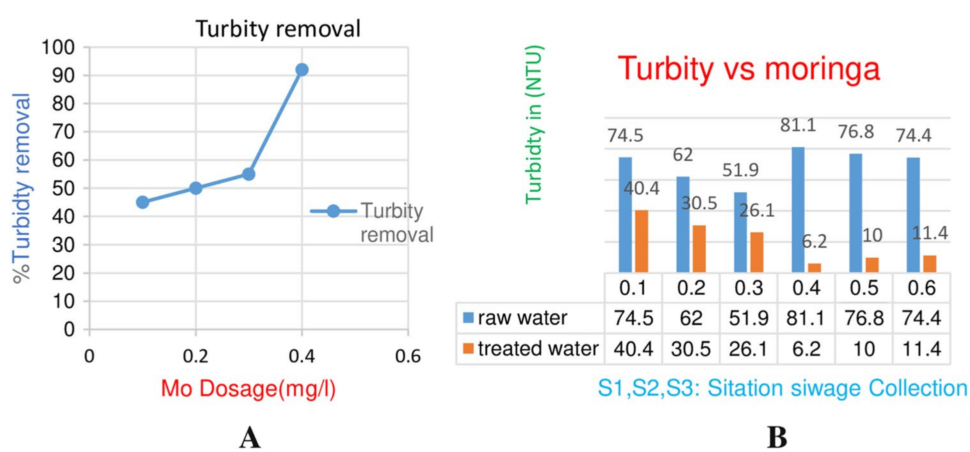


Fig. 3 **A** is a Graph indicating the percentage removal of turbidity and **B** the changes in the turbidity level of water in the sample location to show the effectiveness of using moringa for treating water

- Electrical conductivity (EC): A moderate decrease in EC values post-treatment suggests a reduction in dissolved salts. This is a positive outcome, indicating that *Moringa oleifera* contributes to improved water quality by addressing conductivity-related issues.
- Total solids (TS), total dissolved solids (TDS), and total suspended solids (TSS): Significant reductions in TS, TDS, and TSS emphasize the efficiency of *Moringa oleifera* in removing both suspended and dissolved solids. This is vital for enhancing water clarity and preventing the accumulation of undesirable particles.

Chemical parameters analysis: The study delved into chemical parameters to assess the impact of *Moringa oleifera* treatment on water composition.

- Alkalinity, hardness, and chloride: Notable reductions in alkalinity, hardness, and chloride levels post-treatment signify the plant's efficacy in removing minerals and impurities. This has implications for the taste, odor, and overall quality of the treated water.
- Nitrate, nitrite, and inorganic phosphorus: Varied responses in nutrient levels highlight *Moringa oleifera*'s selectivity in nutrient removal. This underscores the need for site-specific optimization to address the unique composition of different water sources.
- Sulphate and silicate: Moderate reductions in sulfate and silicate concentrations demonstrate *Moringa oleifera*'s versatility in addressing diverse impurities. The plant's ability to target various chemical components contributes to its efficacy in improving water quality.
- Sodium: Efficient reduction in sodium levels is significant for improving water quality for consumption. Elevated sodium levels can pose health risks, and *Moringa oleifera*'s effectiveness in mitigating this is a positive outcome.
- The results of this study demonstrate that the use of *Moringa oleifera* in treating sewage water is effective in improving water quality by reducing turbidity and COD levels. The removal efficiency of *Moringa oleifera* was as high as 92% for some samples, indicating that it is a promising and effective solution for treating wastewater. The reduction in turbidity was likely due to the coagulation and sedimentation properties of *Moringa oleifera*, while the reduction in COD levels can be attributed to the adsorption and coagulation of pollutants by the *Moringa oleifera* seeds

Comparison with other research: Comparisons with existing research provide valuable insights into the broader context of *Moringa oleifera*'s application in water treatment. The study's findings align with the documented efficacy of *Moringa oleifera* as a natural coagulant. Varied environmental conditions may influence optimal dosages for this study the optimal dosage was 0.4 g/1000 mL at a rate of 92% Turbidity removal, while the previous study found [22] 0.3 g/500 mL, and another study [36] found 200 g/L at rate of 88.8% impurities remover, [37] This research also finds the Turbidity removal was at 90 g/L for all study evaluated emphasizing the need for context-specific application areas depends kind of water used and quantity of sample. This suggests that *Moringa oleifera*'s effectiveness is robust but requires adaptation to local conditions for maximum impact.

Based on the relevant studies, it is evident that *Moringa oleifera* has been extensively studied for its potential application as a natural coagulant in sustainable sewage water treatment. The research on natural coagulants from plant-based materials has been focused on *Moringa oleifera*. Studies have shown that *Moringa oleifera* is highly effective as a natural coagulant for turbidity removal [38]. Furthermore, the plant-based natural coagulant has the potential to substitute chemical coagulants in the water treatment process. This is significant as it aligns with the global trend towards sustainable and eco-friendly water treatment technologies.

Moreover, the use of plant-based coagulants, including *Moringa oleifera*, has been explored for the treatment of wastewater, aiming to enhance effluent quality. The potential of natural coagulants, including those derived from plant-based materials, has been recognized as an eco-friendly alternative technology to conventional coagulants for both turbidity and cyanobacteria removal in drinking water treatment plants. This highlights the broader applicability of natural coagulants in addressing water treatment challenges.

Additionally, the indirect application of natural coagulants, including those derived from *Moringa oleifera*, has been emphasized as an essential step for implementing green water and wastewater treatment technologies [17]. This underscores the importance of integrating natural coagulants into sustainable wastewater management practices.

The research on *Moringa oleifera* as a natural coagulant for sustainable sewage water treatment is well-supported by the relevant references. The potential of *Moringa oleifera* and other plant-based coagulants in enhancing water quality, substituting chemical coagulants, and addressing water treatment challenges aligns with the global shift towards sustainable and eco-friendly water treatment technologies.

3.3 Advantage of *Moringa oleifera* as a natural plant coagulant

Moringa oleifera is effective in purifying water due to its coagulating and flocculating properties, which can remove impurities and contaminants from water. However, there are also some challenges and opportunities associated with using *Moringa oleifera for* water purification. The green technique of water treatment is the most preferred method of water treatment due to its cost-effectiveness, environmental sustainability, and easier availability, especially in developing countries. The most preferred and efficient natural coagulants are the seeds of *M. oleifera* which hold polyelectrolytes incorporating cationic proteins helping in coagulation, flocculation, and hence water purification [39]. Social and economic benefits: the use of *Moringa oleifera* for water purification can provide social and economic benefits to communities by reducing the burden of waterborne illnesses and improving water quality *Moringa oleifera* is environmentally friendly characteristics the reason that they cut back global warming It will remain essential for mankind's survival and the future development of the world.

Health benefits: *Moringa oleifera* has been shown to have health benefits, including anti-inflammatory and antioxidant properties, which can provide additional health benefits to communities that use it for water purification they are effective for removing all kinds of hardness of water that makes water be used mostly in rural areas and the boundary of several buildings in cities [40]. The Use of extracts from *Moringa oleifera* (MO) is a huge interest for cost-effective as green methods for purifying water and possibly are available. In addition, *Moringa oleifera* is the source of different medical products and provides more information to researchers to evaluate the potential health benefits of using *Moringa oleifera* as a water treatment technique, including its ability to reduce the risk of waterborne illnesses.

To promote the use of natural plant coagulation like *Moringa oleifera* as a green technique for water treatment and increase awareness about the benefits of sustainable and environmentally friendly water treatment methods.

Figure 4 incorporates the different advantages of using *Moringa oliefera* in the context of water health assessment and contributing to the well-being of the community.

3.4 Disadvantage of *Moringa oleifera* in water purification

Seasonal variability: The coagulating properties *of Moringa oleifera can* vary with the seasons and geographical location, making it difficult to achieve consistent results dosage optimization [41]: the effectiveness of *Moringa oleifera for* water purification depends on the optimal dosage, which can vary depending on the source water quality and the specific application.

Scale-up challenges: Scaling up the use of *Moringa oleifera for* water purification can be challenging due to the need for large amounts of plant material, equipment, and labor.

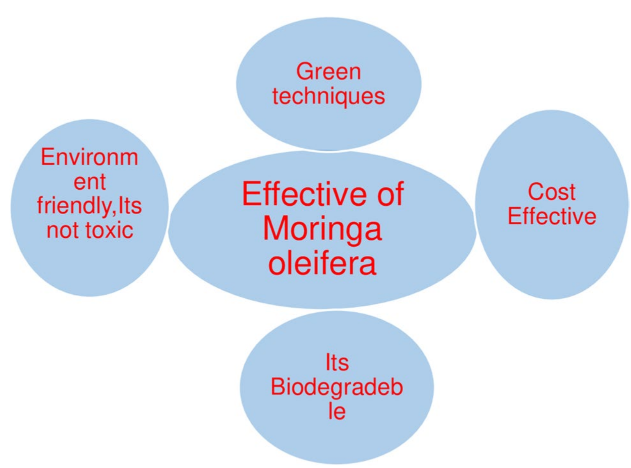
Residual management: After *Moringa oleifera* is used for water purification, the residual sludge must be managed and disposed of properly.

3.5 SWOC analysis of *Moringa oleifera* for treating sewage water

Strengths:

- Effectiveness: *Moringa oleifera* seeds are effective in removing impurities and contaminants from water, including bacteria, viruses, and sediment.
- Low cost: *Moringa oleifera* seeds are readily available and affordable, making them a cost-effective option for water treatment in low-resource settings.

Fig. 4 Eps: the effectiveness of *Moringa oleifera* in treating water



- Sustainability: *Moringa oleifera* is a fast-growing tree that is easy to cultivate and requires little water, making it a sustainable option for water treatment.
- Safe and natural: *Moringa oleifera* is a natural substance that is safe for human consumption, and it does not introduce harmful chemicals or byproducts into the water.

Weaknesses:

- Limited scalability: *Moringa oleifera* seeds may not be a feasible option for large-scale water treatment due to the number of seeds required and the labor-intensive process of extracting the active ingredients.
- Limited research: While *Moringa oleifera* has shown promise in small-scale water treatment, there is limited research on its long-term effectiveness and feasibility for large-scale applications.
- Variability: The effectiveness of *Moringa oleifera* seeds can vary depending on factors such as seed quality, water quality, and extraction methods.

Opportunities:

- Innovation: Advances in technology and processes could make it easier and more efficient to extract and apply the active ingredients in *Moringa oleifera* seeds for water treatment.
- Increased research: As interest in *Moringa oleifera* for water treatment grows, there is an opportunity for more research to be conducted to determine its effectiveness and potential applications.
- Partnerships: Collaboration between researchers, organizations, and communities could help to scale up the use of *Moringa oleifera* seeds for water treatment in areas where access to clean water is limited.

Challenge:

- Lack of awareness: Many communities may not be aware of the potential benefits of using *Moringa oleifera* seeds for water treatment, which could limit its adoption.
- Competition from other water treatment options: *Moringa oleifera* may face competition from other, more established water treatment methods, which could limit its market penetration.

Environmental factors: Climate change and other environmental factors could impact the growth and availability of *Moringa oleifera*, which could affect its feasibility as a water treatment option.

3.6 Conclusion

In conclusion, this study has provided valuable insights into the effectiveness of *Moringa oleifera* as a natural coagulant for sustainable sewage water treatment. The significant reduction in turbidity levels across various sampling points demonstrates the plant's strong coagulant properties. The optimal dosage of 0.4 g/1000 mL and treatment conditions yielded remarkable outcomes, reinforcing *Moringa oleifera*'s potential for improving water clarity through natural coagulation. The analysis of physical and chemical parameters further supported the plant's efficacy in addressing a range of impurities, including dissolved and suspended solids, minerals, and nutrients. The study's success in achieving its objectives underscores *Moringa oleifera* as a cost-effective and environmentally friendly solution for decentralized sewage water treatment. The plant's ability to target diverse impurities and its adaptability to different environmental conditions make it a promising candidate for wider application, especially in regions facing water scarcity and lacking access to conventional treatment methods. However, certain challenges and opportunities emerged from the research. The study identified the need for further optimization to address site-specific variations and enhance the consistency of results. Fine-tuning dosage and treatment conditions based on local water characteristics could contribute to the scalability and reliability of *Moringa oleifera*-based treatment systems. The study also highlighted the importance of tailoring treatment strategies to specific environmental conditions, emphasizing the need for context-specific applications. Future research endeavors should build upon the findings of this study to advance the application of *Moringa oleifera* in sewage water treatment. Several avenues warrant exploration:

Optimization strategies Further investigations can delve into refining dosage and treatment parameters for *Moringa oleifera*. This includes exploring variations in dosage based on specific water compositions and environmental conditions to achieve optimal and consistent results.

Integration with Conventional *Treatment*: Future studies can explore the integration of *Moringa oleifera* with conventional water treatment methods. Assessing the plant's compatibility with existing treatment processes can enhance its potential for broader application in larger water treatment systems.

Long-term performance and stability Evaluating the long-term performance and stability of *Moringa oleifera*-based treatment systems is crucial. Understanding the longevity of the plant's coagulant properties and its resilience to changing environmental conditions will inform the sustainability of such solutions.

Economic viability and community impact Assessing the economic viability of implementing *Moringa oleifera*-based treatment on a larger scale is essential. Additionally, studies can investigate the social and community impact of adopting such decentralized water treatment solutions, considering factors such as accessibility, cultural acceptance, and community involvement.

Comparative studies Comparative studies with other natural coagulants and conventional treatment methods can provide a comprehensive understanding of *Moringa oleifera*'s efficacy and advantages. Identifying its unique strengths and potential limitations in comparison to alternative treatments will contribute to informed decision-making.

Regional adaptation Given the plant's sensitivity to local conditions, future research can focus on adapting *Moringa oleifera* treatment strategies to specific regions. This involves considering variations in climate, water quality, and cultural practices to ensure optimal performance.

Water quality standards Aligning *Moringa oleifera*-based treatment with established water quality standards and regulatory guidelines is crucial. Future studies should assess compliance with global and regional standards to validate the plant's suitability for widespread adoption.

In summary, the results of this study demonstrate the potential of *Moringa oleifera as* an effective and affordable option for treating sewage water. The coagulation and sedimentation properties of *Moringa oleifera* seeds were found to be effective in reducing turbidity levels in sewage water. The reduction in COD levels indicates that *Moringa oleifera* was able to remove organic and inorganic pollutants from the sewage water. The study of this work demonstrated that *Moringa oleifera* can effectively treat sewage water, with significant reductions in turbidity, total solids, total suspended solids, total dissolved solids, hardness, chloride, fluoride, sulfate, inorganic phosphorus, and COD levels. The study highlights the potential of *Moringa oleifera* as an alternative and sustainable solution for sewage water treatment. The current study serves as a foundation for advancing the application of *Moringa oleifera* in sustainable sewage water treatment. Future research endeavors should explore optimization strategies, integration with conventional treatment, long-term performance, economic viability, community impact, comparative studies, regional adaptation, and adherence to water quality standards. By addressing these aspects, researchers can contribute to the development of robust and scalable solutions that harness the potential of *Moringa oleifera* for addressing global water challenges.

Author contributions B.S. Nzeyimana contributed to the following activities: material preparation, data collection, analysis, and first draft of the manuscript. While A.D.C. Mary contributed to the Correction and Analysis with comments on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability The data that support the findings of this study are available after the publication of this article and can be obtained through request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication All authors of this research paper have provided their full consent for the publication of this work. We unanimously agree with the content, findings, and its submission for publication.

Competing interests The authors have no relevant financial or non-financial interests to disclose.

References

1. Shayo GM, Elimbinzi E, Shao GN, Fabian C. Severity of waterborne diseases in developing countries and the effectiveness of ceramic filters for improving water quality. Bull Natl Res Cent. 2023;47(1):113. https://doi.org/10.1186/s42269-023-01088-9.
2. Gall AM, Mariñas BJ, Lu Y, Shisler JL. Waterborne viruses: a barrier to safe drinking water. PLoS Pathog. 2015;11(6):1–7. https://doi.org/10.1371/journal.ppat.1004867.
3. Our World in Data team. Ensure access to water and sanitation for all. Our World in Data. 2023. https://ourworldindata.org/sdgs/clean-water-sanitation
4. Xiong B, et al. *Moringa oleifera* f-sand filters for sustainable water purification. Environ Sci Technol Lett. 2017. https://doi.org/10.1021/acs.estlett.7b00490.
5. Bouchareb R, Derbal K, Benalia A. Optimization of active coagulant agent extraction method from *Moringa oleifera* seeds for municipal wastewater treatment. Water Sci Technol. 2021;84(2):393–403. https://doi.org/10.2166/wst.2021.234.
6. Kasmuri N, et al. Treatment of wastewater by *Moringa oleifera* and maize seeds as plant-based coagulant. IOP Conf Ser Earth Environ Sci. 2023. https://doi.org/10.1088/1755-1315/1140/1/012010.
7. El Bouaidi W, et al. Nature-based coagulants for drinking water treatment: an ecotoxicological overview. Water Environ Res. 2022;94(8):1–13. https://doi.org/10.1002/wer.10782.
8. Bouchareb R, Derbal K, Özay Y, Bilici Z, Dizge N. Combined natural/chemical coagulation and membrane filtration for wood processing wastewater treatment. J Water Process Eng. 2020;37(May): 101521. https://doi.org/10.1016/j.jwpe.2020.101521.
9. Benalia A, et al. Use of aloe vera as an organic coagulant for improving drinking water quality. Water. 2021;13(15):2024. https://doi.org/10.3390/w13152024.
10. Ndabigengesere A, Subba Narasiah K. Quality of water treated by coagulation using *Moringa oleifera* seeds. Water Res. 1998;32(3):781–91. https://doi.org/10.1016/S0043-1354(97)00295-9.
11. Crini G, Lichtfouse E. Advantages and disadvantages of techniques used for wastewater treatment. Environ Chem Lett. 2019;17(1):145–55. https://doi.org/10.1007/s10311-018-0785-9.
12. Ho JH, Khanal SK, Sung S. Anaerobic membrane bioreactor for treatment of synthetic municipal wastewater at ambient temperature. Water Sci Technol. 2007;55(7):79–86. https://doi.org/10.2166/wst.2007.130.
13. Rasheed FA, Alkaradaghi K, Al-Ansari N. The potential of *Moringa oleifera* seed in water coagulation–flocculation technique to reduce water turbidity. Water Air Soil Pollut. 2023;234(4):250. https://doi.org/10.1007/s11270-023-06238-3.
14. Quintero-Jaramillo JA, Murillo-Arango W, Cerón-Salazar IX. Use of thermal water as a natural coagulant for domestic wastewater sustainable treatment. Rev Fac Ing. 2017;26(44):35–45. https://doi.org/10.19053/01211129.v26.n44.2017.5770.
15. United States EPA 833-F-98-002 Environmental Protection May. Agency Office of Water (4204), 1998.
16. Criscuoli A, Rossi E, Cofone F, Drioli E. Boron removal by membrane contactors: the water that purifies water. Clean Technol Environ Policy. 2010;12(1):53–61. https://doi.org/10.1007/s10098-009-0221-8.
17. Alazaiza MYD, et al. Application of natural coagulants for pharmaceutical removal from water and wastewater: a review. Water. 2022;14(2):1–16. https://doi.org/10.3390/w14020140.
18. Aho IM, Lagasi JE. A new water treatment system using *Moringa oleifera* seed. Am J Sci Ind Res. 2012;3(6):1–6. https://doi.org/10.5251/ajsir.2012.3.6.487.492.
19. Kumar U, Thakur AS. Sustainable treatment of water and wastewater using natural plant-based coagulants: a review. Int J Eng Res Technol. 2022;11(05):650–6.
20. Gaikwad V, Munavalli G. Treatability study for river water with *Moringa oleifera* and Nirmali seeds. Int J Res Eng Technol. 2016;05(30):50–4. https://doi.org/10.15623/ijret.2016.0530007.
21. Beletini LF, et al. Influence of coagulant *Moringa oleifera* seed extract on reduction of *Toxoplasma gondii* oocysts and viability of *Toxocara* spp. eggs in water. Desalin Water Treat. 2019;167:38–44. https://doi.org/10.5004/dwt.2019.24311.
22. Desta WM, Bote ME. Heliyon wastewater treatment using a natural coagulant (*Moringa oleifera* seeds): optimization through response surface methodology. Heliyon. 2021;7(8): e08451. https://doi.org/10.1016/j.heliyon.2021.e08451.
23. Muyibi SA, Abbas SA, Noor MJMM, Noor M, Ahmadun NFR. Enhanced coagulation efficiency of *Moringa oleifera* seeds through selective oil extraction. IIUM Eng J. 1970. https://doi.org/10.31436/iiumej.v4i1.366.
24. Ueda Yamaguchi N, et al. A review of *Moringa oleifera* seeds in water treatment: trends and future challenges. Process Saf Environ Prot. 2021;147(4):405–20. https://doi.org/10.1016/j.psep.2020.09.044.
25. Deswal S, Rawat S, Kumar S, Sangwan V. Potential of *Moringa oleifera* and Okra as Coagulants in sustainable treatment of water and wastewater. Ecol Quest. 2023;34(4):1–17. https://doi.org/10.12775/eq.2023.045.
26. de La Grange I, Prasasty VD. A study on the removal of pesticide residues on potatoes using *Moringa oleifera* seed as a food safety measure. Int J Hortic Agric Food Sci. 2019;3(5):254–61. https://doi.org/10.22161/ijhaf.3.5.2.
27. Abeykoon AMH, et al. *Coxiella burnetii* in the environment: a systematic review and critical appraisal of sampling methods. Zoonoses Public Health. 2021;68(3):165–81. https://doi.org/10.1111/zph.12791.
28. Zarowsky C. Evaluation of the natural coagulant *Moringa oleifera* as a pretreatment for SODIS in contaminated turbid water. Sol Energy. 2017;158(September):448–54. https://doi.org/10.1016/j.solener.2017.10.010.
29. Ribeiro T, et al. Magnetic natural coagulants for plastic recycling industry wastewater treatability. Water. 2023;15(7):1–15. https://doi.org/10.3390/w15071276.
30. Owodunni AA, Ismail S. Revolutionary technique for sustainable plant-based green coagulants in industrial wastewater treatment—a review. J Water Process Eng. 2021;42(2): 102096. https://doi.org/10.1016/j.jwpe.2021.102096.

31. Taiwo AS, Adenike K, Aderonke O. Efficacy of a natural coagulant protein from *Moringa oleifera* (Lam) seeds in treatment of Opa reservoir water, Ile-Ife, Nigeria. Heliyon. 2020;6(1): e03335. https://doi.org/10.1016/j.heliyon.2020.e03335.
32. Ali EN. Removal of copper from water system using *Moringa oleifera* press cake. In: International conference on agricultural, civil and environmental engineering. 2016. p. 16–19. https://doi.org/10.17758/uruae.ae0416214.
33. Liang L, Wang C, Li S, Chu X, Sun K. Nutritional compositions of Indian *Moringa oleifera* seed and antioxidant activity of its polypeptides. Food Sci Nutr. 2019;7(5):1754–60. https://doi.org/10.1002/fsn3.1015.
34. Idris J, et al. Dragon fruit foliage plant-based coagulant for treatment of concentrated latex effluent: comparison of treatment with ferric sulfate. J Chem. 2013. https://doi.org/10.1155/2013/230860.
35. Vunain E, Masoamphambe EF, Mpeketula PMG, Monjerezi M, Etale A. Evaluation of coagulating efficiency and water borne pathogens reduction capacity of *Moringa oleifera* seed powder for treatment of domestic wastewater from Zomba, Malawi. J Environ Chem Eng. 2019;7(3): 103118. https://doi.org/10.1016/j.jece.2019.103118.
36. Reddemma S, Rajesh K, Ramesh B, Tejeswini G, Pavan B, Amarendra D. Removal of turbidity by using *Moringa oliefera*. Int J Innov Res Comput Sci Technol. 2023;11(1):82–6. https://doi.org/10.55524/ijircst.2023.11.1.16.
37. Yusuf J, Yuakubu MB, Balarabe AM. The use of *Moringa oleifera* seed as a coagulant for domestic water purification. IOSR J Pharm Biol Sci Ver III. 2021;10(1):2319–7676. https://doi.org/10.9790/3008-10130609.
38. Bhatnagar A, Sillanpää M. Utilization of agro-industrial and municipal waste materials as potential adsorbents for water treatment—a review. Chem Eng J. 2010;157(2–3):277–96. https://doi.org/10.1016/j.cej.2010.01.007.
39. Dhakad AK, Ikram M, Sharma S, Khan S, Pandey VV, Singh A. Biological, nutritional, and therapeutic significance of *Moringa oleifera* Lam. Phyther Res. 2019;33(11):2870–903. https://doi.org/10.1002/ptr.6475.
40. Meena R, et al. Application of *Moringa oleifera* in dentistry. Asian J Dent Health Sci. 2021;1(1):10–3. https://doi.org/10.22270/ajdhs.v1i1.5.
41. Awad M, Wang H, Li F. Weaknesses of *Moringa oleifera* use in water treatment. Artic Int J Curr Res. 2013;5:1165–7.