VOL 7(2), 193-213
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ISSN: 2523-1901 (Online)
URL: http://jessd.mwu.edu.et/
Email: JESSDeditorials@mwu.edu.et
JESSD Journal of Equity in Sciences & Sustainable Development

DOI: https: //doi.org/10.20372/mwu.jessd.2024.1562

Full Length Research Paper

Treatment of turbid surface water using Oppuntia ficus-indica as a plant-based coagulant

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Article Info

Article History

Received: 01 Nov 2023

Accepted: 12 April 2024

Keywords:

Mucilage, Opuntia ficus-indica, Plant-based coagulants, Turbidity, Surface water

Abstract

Researchers are looking for sustainable alternatives to address current issues related to water quality because developing countries often lack access to suitable water treatment technologies and pose health dangers in both rural and urban areas. Plant species have shown promising results for use in turbid water treatment. In this context, Opuntia ficus-indica was tested for its ability to reduce the turbidity of surface water and synthetic kaolinite suspensions. The field and experimental research was carried out was conducted from February 2021 to March 2022. Coagulation tests were performed as part of the experimental investigation in the Laboratory of the Biology Department of Madda Walabu University. Total dissolved solids, electrical conductivity, temperature, turbidity, and pH were measured for water physicochemical examination according to the protocol. Doses ranging from 10 mg/L to 50 mg/L were used to investigate how the dose affects the reduction in turbidity. The impact of initial turbidity on the effectiveness of coagulation was studied using surface (33 ntu) and synthetic water (60 and 100 ntu) samples. All experiments were conducted in duplicate and the means were calculated. According to the study findings, O. ficus-indica reduced turbidity to 5ntu at the optimal dose of 20 mg / L in 33 ntu, 40 mg / L in 60 ntu and 100 ntu using 0.5 NaCl as a solvent. The efficiency of O. ficus indica removal in turbid river water was 85%. Using synthetic turbid water, O. ficus-indica extracts showed 91.6% turbidity removal efficiency at 60 ntu, whereas at 100 ntu, the extracts showed 95% turbidity removal efficiency. At pH 8, O. ficus-indica performed best (87% turbidity removal efficiency). The pH of the river water samples was only minimally altered by coagulation with extracts of O. ficus-indica. The same river water that was treated with alum had a pH that was reduced from 6.5 to 3.45, making the water acidic. According to the results of the present study, O. ficus indica is a viable substitute for turbid surface water because it effectively eliminates turbidity. By guaranteeing water availability and sustainable management, this species can be crucial to achieving one of the Sustainable Development Goals.

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1. Introduction

Water is vital for sustainable development and human survival (UN, 2014). However, in both developed and developing worlds, the goal of delivering safe water in a sustainable manner remains undone due to current obstacles. The intensive use of chemicals and energy requires a considerable infusion of capital, engineering expertise, and infrastructure, which are considered obstacles and prevent their use worldwide (Shannon et al., 2008). The water utilities in the developed world are facing significant challenges because they are fully compliant with existing water quality regulations (Ghernaout et al., 2011). Furthermore, chemically intensive treatment methods cannot be used in many regions of the world due to the lack of appropriate infrastructure (Shannon et al., 2008). Chlorine and aluminum compounds used to reduce the risk of infectious diseases may account for a substantial portion of the health risk associated with drinking water by forming by-products (Daiber et al., 2016). For example, aluminum compounds have potential links to Alzheimer's disease and cancer (Rondeau et al., 2009; Bodlund et al., 2014). Furthermore, the wide use of alum-based coagulants has also exhibited several drawbacks, such as the production of large volumes of sludge and a considerable reduction in the pH of treated water, as well as the natural alkalinity of water (Vijayaraghavan et al., 2011). The target 6 of the Sustainable Development Goals (SDGs), which seeks to guarantee the availability and sustainable management of water for all, is questioned (UN, 2014). The goal addresses concerns about drinking water, sanitation, and hygiene in addition to global sustainability and quality of water supplies.

Despite efforts toward universal coverage of safe drinking water, 2.2 billion people still lacked access to safe drinking water (UNICEF, 2023). Of these, 1.5 billion had access to basic services, 292 million had limited services, 296 million had unimproved services, and 115 million had access to surface water. This problem is particularly severe in sub-Saharan Africa, where just 31% of people (UNICEF, 2023) and 13% of Ethiopians have access to managed safe water services (Bastin et al., 2019). Where access to safe and managed water is still a distant dream, there is an urgent need to find more appropriate and cost-effective methods for water treatment (Pritchard et al., 2016). This strategy might also constitute the most effective way to provide safe water to underdeveloped or rural areas without adequate water treatment infrastructure (Miller et al., 2018).

Certain plant species have been reported to be used as the main coagulant in the treatment of turbid water. The reported species include *Aloe vera* (Benalia et al., 2021), *Moringa oleifera* (Varkey, 2020; Vigneshwaran et al., 2020; Hadadi et al., 2022; Konkobo et al., 2023), *Moringa stenopetala* (Megersa et al., 2016; Haligamo et al., 2020), *Maerua subcordata* (Megersa et al., 2016), *Cactus species* (Miller et al., 2008; Hadadi et al., 2022; Zhang et al., 2006; Pichler et al., 2012; Beyene et al., 2016; Iqbal et al., 2016), *Carica papaya* (Yimer et al., 2021), *Azadirachta indica, Piper sarmentosum* (Ahmad et al., 2021), *Musa cavendish* (Azamzam et al., 2022), *Pinus halepensis* (Hadadi et al., 2022), *Mangifera indica* (Onyutha and Auma, 2023), *Strychnos potatorum* (Sheeba et al., 2023), Banana pith (Zainol et al., 2023) and Oat and Onion (Mahanna et al., 2023). The most researched natural coagulant among the species is *M. oleifera*, whose effectiveness in removing turbidity has been documented.

O. ficus-indica has already been used as a plant-based coagulant to treat turbid water, waste water, and color removal. The mucilage obtained from the peel of *O. ficus-indica* fruit as a primary coagulant for the removal of turbidity and color in synthetic turbid water indicated its effectiveness (Otalora et al., 2022). The authors also indicated that the optimal dose to treat 54.33 ntu was 12 mg/L at pH 13. In a similar study (Wan et al., 2019), indicated that *O. ficus-indica* had a turbidity removal efficiency comparable to that of alum. However, a higher dose of 900 mg/L was used than that of alum (190 mg/L), which removed 98% of the turbidity in the water from the tailings pond. Furthermore, the improvement of the electrocoagulation–electro flotation process by a natural coagulant extracted from *O. ficus indica* was investigated (Adjeroud-Abdellatif et al., 2022). A recent study using a mixture of cactus-banana peels as a natural coagulant for the removal of turbidity showed that the optimal ratio of cactus to banana was 0.62: 0.38 (Kalibbala et al., 2023).

Various researchers have reported the importance of *O. ficus-indica* in wastewater treatment. Chemically modified cladodes of the *O. ficus-indica* cladodes removed Pb (II), Cd (II), Ni (II), Cu (II), Fe, Mn, Cr and As, (Vargas-Solano et al., 2022; Barbera et al., 2023; Lavado-Meza et al., 2023) and methylene blue (Ihaddaden et al., 2022) from aqueous media. A combined coagulation-electrocoagulation process of a biocoagulant from *O. ficus-indica* was used for the treatment of cheese whey waste water. At a pH of 10 and a bio coagulant dosage of 4.4 g/L, the turbidity and the removal efficiency of the chemical oxygen demand were 98% and 83.8%, respectively (Pacheco et al., 2023). In a recent study Hocine et al. (2023) reported that *O. ficus-indica* can be used as a bioflocculant to conditioning sewage sludge.

Although proteins from various plant species have been reported to have coagulation properties, the availability of similar amounts of proteins among different plant species does not result in similar turbidity removal capabilities (Bodlund et al., 2014). The turbidity removal properties of a single species also vary depending on the type of climate, soil content, crop year, and geographical features (Narasiah et al., 2022; Pritchard et al., 2009). A recent study on the turbidity removal efficiency of seed kernels of *M. indica* genotypes indicated that there is variation in the turbidity removal efficiency among genotypes due to protein content (Onyutha and Auma, 2023).

Many reports on the turbidity removal efficiency of *O. ficus-indica* have also been conducted using turbid model water with varying efficiencies, but these reports cannot reflect the exact nature of surface water. The characteristics of raw water have been reported to play a significant role in determining the effectiveness of coagulation (Pritchard et al., 2009). For example, a change in pH can improve the efficiency of the coagulation process, as it changes the electrochemical properties of the ionic polymers and the solvent used (Somasundaran et al., 2005). The ability of a plant species to remove turbidity is also influenced by the amount of colloidal particles present in the water. Therefore, the present study investigates the efficiency of *O. ficus*-indica on surface water and artificial water samples made with a clay kaolin solution. Numerous factors were taken into account, including the type of solvent, pH, coagulant dose, and initial turbidity. We hypothesized that the pH, type of solvent coagulants dose and initial turbidity affect the coagulation potential of *O. ficus-indica*.

2. Materials and Methods

2.1. Plant description

The genus *Opuntia* is the largest in the *Cactaceae* family and is found in arid and semi-arid parts of the world (Choudhary et al., 2019). *O. ficus-indica* grows widely in the Tigray region and in the Bale zone of Oromia and is consumed as a supplementary food source. The plant is locally known as 'Beles' in Tigrinya and 'Shookaa' in Afan Oromo. According to reports, plants help to prevent desertification and climate change, while also encouraging water conservation (Jacobo et al., 2001). Selected *Oppuntia* spp. were shown to have fibers, minerals, sugars, acids, and phenols in physicochemical studies (Choudhary et al., 2019, Ayadi et al., 2009). A significant amount of carbohydrates can be found in the mucilaginous jelly of the cladodes of Cactus (Albergamo et al., 2022). According to phytochemical analysis, arabinose, rhamnose, xylose, galactose, glucose, and galacturonic acid are found in the mucilage of *O. ficus-indica* (Ginestra et al., 2009).

2.2. Collection and preparation of coagulants

The fruits of *O. ficus indica* (Figure 1A) were collected from a local market in Donsa, Robe town, whereas the pads (Figure 1B) were collected from Robe town, Oromia regional state, Ethiopia. Deionized water was used to carefully clean the pads. Fresh *O. ficus indica* plants were used one to three days after harvest and stored in a refrigerator at 4°C when not used. The dried *O. ficus indica* was prepared by cutting fresh species and drying them for 3 days in strong natural sunlight. *O. ficus indica* was subsequently ground in a coffee grinder (Nima, Japan). According to Somasundaran et al. (2005), *O. ficus indica* powder was stored in an airtight container at 4°C in a refrigerator. The powder of *O. ficus indica* were used to extract active components in deionized water and salt solutions at concentrations of 0.1, 0.5, 1 and 1.5 M NaCl. The crude extracts were then kept at room temperature as a final step. For the investigation, 5% (w/v) aluminum sulfate was used as a positive control.

Figure 1: (A) Fruits of *O. ficus indica.* (B) Pad of *O. ficus indica* used for turbidity reduction.

2.3. Water sample preparation

Surface water samples were taken from the Shaya River in Robe, Ethiopia. Surface water samples were taken during the dry season in the months of September and October 2021, when the initial turbidity of the river was 33 ntu. The TDS, EC, T^0, and pH for the physicochemical analysis of water were measured based on conventional methods (APHA, 2005). The TDS, T^0, turbidity and pH were measured on site while the EC was measured in laboratory. The turbidity of each water sample was measured using a portable turbid meter (WG2-1, 2100Q, HACH) before, during and after a settling time of 0.5 hours over a period of five hours. All experiments were conducted in duplicate and the means were calculated. The apparatus was also calibrated with turbidity standards. Electrical conductivity (EC) and total dissolved solids (TDS) were measured using a microprocessor-based conductivity/TDS meter (Model= 1601). A pH or temperature meter (PH-13) was used to measure temperature and pH. The samples were taken in sterile, thoroughly clean polyethylene plastic bottles. The samples were transported to the laboratory, where they were kept in a deep freezer until analysis. To make synthetic turbid water, 10 g of kaolin clay was mixed with 1 L of deionized water. The suspension was agitated for an hour using a magnetic stirrer to obtain a homogeneous dispersion of the kaolin particles (Muyibi and Evison, 1995). After that, the mixture was left to settle for 24 hours to fully hydrate the kaolin. Based on Asrafuzzaman et al. (2011), medium (60 ntu) and high (100 ntu) turbidity ranges were prepared from synthetic water. Dallul Pharmaceuticals in Addis Ababa, Ethiopia, supplied deionized water, while Awash Melkasa in Shoa, Ethiopia, supplied kaolin clay.

2.4. Chemical analysis of the plant

The leaves were subjected to a duplicate analysis. According to AOAC (2007) (AOAC method 925.10), the moisture content was calculated after drying at 130°C. According to AOAC (2000), procedures, crude fat was examined using a Soxhlet apparatus and extraction of petroleum ether. Using the ceramic fiber filter method, the crude fiber was analyzed according to the procedure by AOAC (2000). The protein content was determined based on the ISO1871:2013 method). The ash content was determined using the direct method AOAC 923.03 (2000). The carbohydrate content was determined using the following formula Kalibbala et al. (2023).

% carbohydrates = 100%- (% protein +% lipid +% moisture +% ash +% fiber)

2.5. Determination of inorganic elements

Calcium (Ca) and magnesium (Mg) concentrations were determined using the official modified AOAC 985.35-EDTA titrimetric method (AOAC, 2007). Iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn) were analyzed via atomic absorption spectrometry.

2.6. Batch coagulation experiment

A jar tester (Thermotech Th-6001, Loctron Instruments Pvt. Ltd.) was used in the turbidity removal efficiency tests of the crude extracts (Figure 2). For effective spread of the coagulants, the suspension was stirred rapidly at 170 rpm for 2 minutes. Subsequently, the mixing speed was reduced to 40 rpm for an additional 20 minutes, as indicated Megersa et al. (2017). Six beakers, each one liter in size, were used for batch coagulation experiments. Both positive (turbid water treated with alum) and negative (blank water) water were used as controls. Using an electron scale balance, *O. ficus indica* extracts were added to the other four samples at different concentrations, ranging from 10 to 50 mg/L. The coagulants were added and the solutions were stirred for three minutes before further mixing. The suspensions were allowed to settle for half an hour after the stirring was stopped and the dose that removed the most turbidity was noted.

Using Lee's equation (Lee et al., 1995), the turbidity removal efficiency (TRE) of the extracts was determined as follows:

$$TRE = \frac{T^{\circ} - T}{T^{\circ}} x\ 100$$

where **TRE** is the turbidity removal efficiency, **T°** is the initial turbidity, and **T** is the final turbidity.

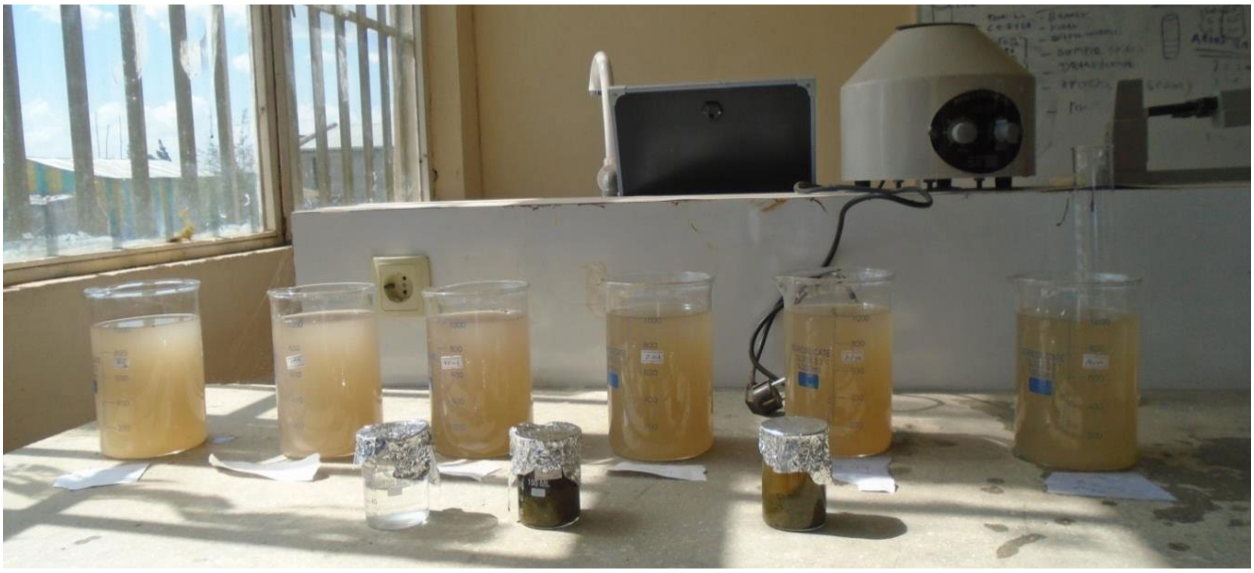

Figure 2: Experiment on coagulation using different doses and alum as a control.

2.6. Effect of pH

Using sodium hydroxide or hydrochloric acid, the initial pH of the water samples was changed to 4, 5, 6, 7, 8, 9, or 10 to examine the impact of pH on plant coagulation activity. A pH meter (pH 13) was used to measure the pH.

3. Results

3.1. Proximate composition

The crude extracts revealed that the *O. ficus-indica* pad had an extremely low crude protein content of 0.02%. The results of the analysis also revealed that the ash and moisture contents were 0.31% and 96.79%, respectively (Table 1). The pad contained the highest amount of calcium (950.15 mg/kg) according to an analysis performed using atomic absorbance spectrophotometry (Table 1).

Table 1: Proximate mineral composition (mg/kg) of *O. ficus-indica* pads.

Sample	Composition in %	Sample	Composition (mg/kg)
Crude moisture	96.79	Ca	950.15
Crude fiber	0.05	Cu	0.36
Crude fat	0.07	Fe	9.58
Crude protein	0.02	Mg	550.37
Ash	0.31	Mn	3.47
Carbohydrates	2.76	Zn	0.41

3.2. The physicochemical characteristics of the Shaya River

Water samples were collected from the Shaya River and discovered that the initial turbidity was 33 NTU. The temperature, conductivity, TDS and pH values were 21.3°C, 92.5 mS/m, 60.45 mg/L, and 6.85, respectively.

3.3. Effect of pH on coagulation performance

In water with a pH range of 4 to 10, the effect of pH on the ability of *O. ficus*-indica to remove turbidity was investigated. At a pH of 10, the least amount of turbidity removal was observed (Figure 3). The extracts of *O. ficus-indica* performed best at pH=8, reducing turbidity by up to 87%. The effectiveness of turbidity reduction decreased to 50% at a pH of 10.

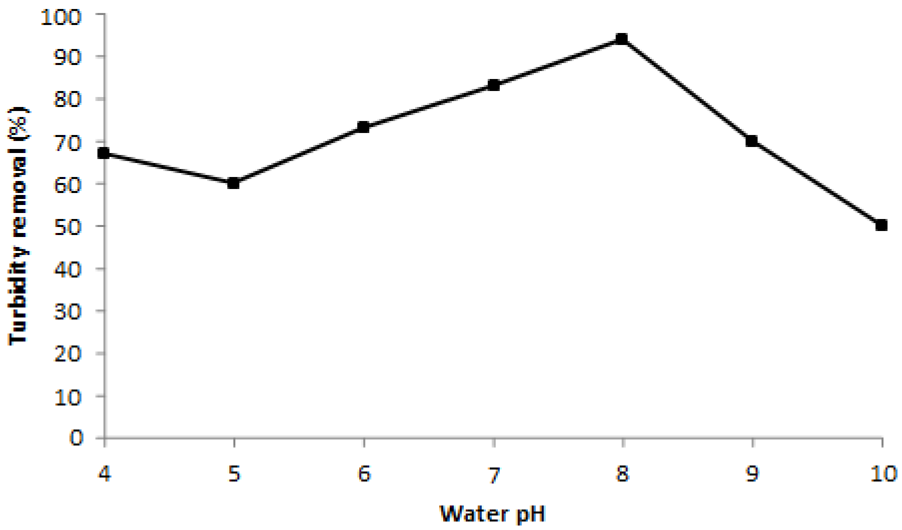

Figure 3: The impact of water pH on the effectiveness of *O. ficus-indica* turbidity reduction.

3.4. Effect of solvent extraction on turbidity removal efficiency

The percentage of turbidity removal varied depending on the concentration of solvent used in the study; a maximum was reached at 0.5 M NaCl. The least turbidity removal was observed at 1.5 M NaCl (Figure 4).

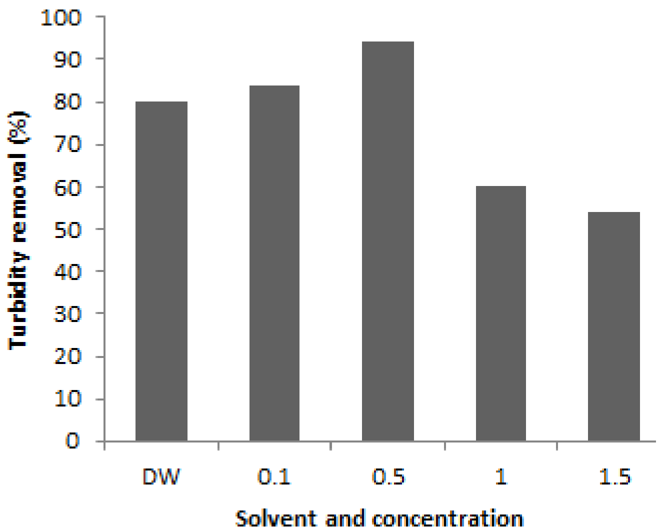

Figure 4: The effect of extraction solvent on turbidity reduction.

3.5. Effects of dosage and initial turbidity on the efficiency of coagulants

Since different sources of river water can have varying levels of turbidity, a crucial factor that requires careful study is the effect of initial turbidity on the efficacy of turbidity removal. To investigate the impact of initial turbidity on the efficiency of *O. ficus indica,* three turbidity levels, 33, 60, and 100 ntu, were applied under optimal conditions, pH 8 and 0.5 M NaCl. Figure 5 shows that as initial turbidity increased from low to high, the percentage of turbidity reduction also increased. Figure 5 shows that the optimal dose to reduce turbidity at 33 ntu was 20 mg/L, whereas Figures 6 and 7 show that the ideal doses at 60 and 100 ntu were 40 mg/L.

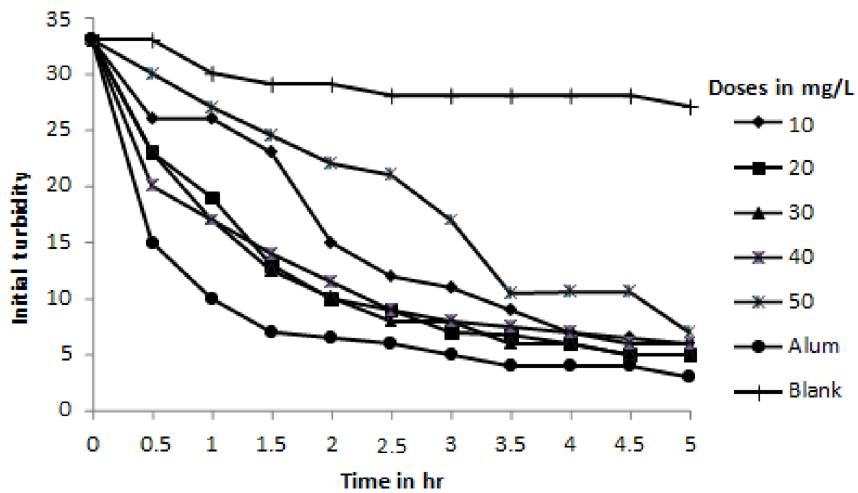

Figure 5: Effect of the coagulant dose on the removal of turbidity at an initial turbidity of 33 ntu.

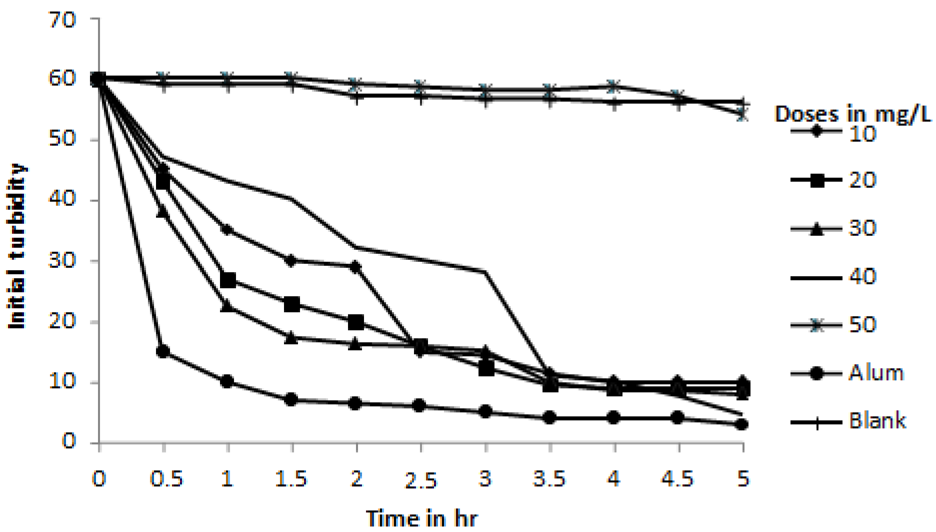

Figure 6: Effect of the coagulant dose on the removal of turbidity at an initial turbidity of 60 ntu.

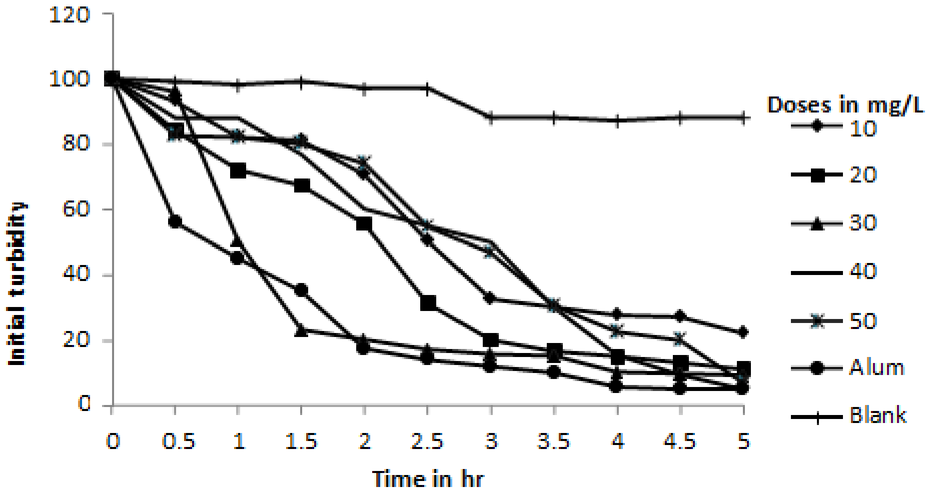

Figure 7: Effect of the coagulant dose on the removal of turbidity at an initial turbidity of 100 ntu.

3.6. Effect of coagulants on the pH of water

The pH of the river water samples was only minimally altered by the coagulation process using extracts of O. ficus-indica (Figure 8). The alum treatment reduced the pH of the same river water from 6.5 to 3.45, making it much more acidic.

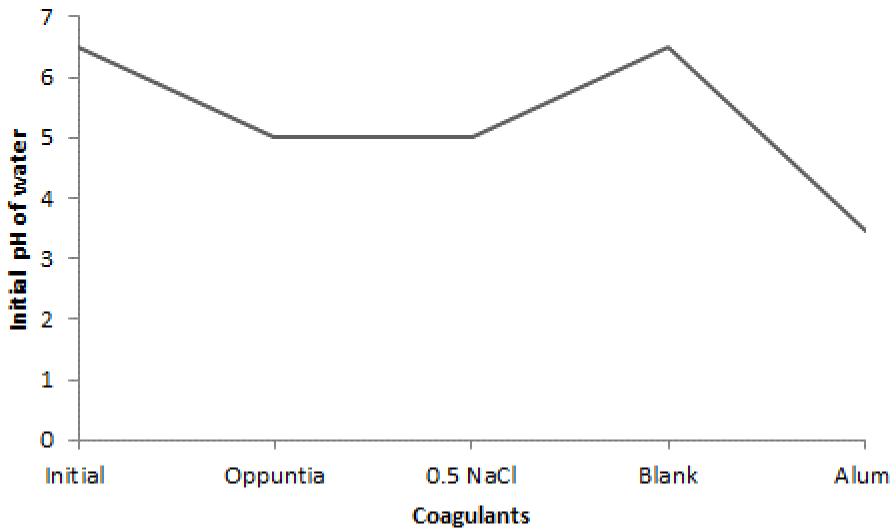

Figure 8: Changes in pH of water samples treated with *O. ficus-indica* and alum as a control.

4. Discussion

It has long been common practice to purify water from different plant species, but this process has variable degrees of success (Sanghi et al., 2002). The present study evaluated the liquid form of the coagulant from *O. ficus-indica*. However, the powder form of plant species could also be used to treat turbid water. For example, powders obtained from *M. oleifera* seeds (Madsen et al., 1987), tubers of *M. subcordata* and *M. stenopetala* (Megersa et al., 2016) and Pomegranate seed (Shabanizadeh et al., 2023) proved to be effective alternative coagulants used to treat turbid river water. This approach may be cost-effective, but has drawbacks in that the prepared powder contains not only coagulating active agents but also other less important molecules and could increase organic loadings in treated water, in turn exacerbating the situation rather than enhancing the treatment (Ghebremichael et al., 2005; Yin, 2010). Furthermore, several studies have confirmed that liquid plant coagulants have better turbidity removal efficiency than powder plant coagulants (Onyutha and Auma, 2023). For example, Acorn reduced the turbidity of water at 13ntu by 71.6% and 84.77% when used in powder and liquid form, respectively (Benalia et al., 2019). *A. vera* powder and liquid form had turbidity removal efficiencies of 28.2 and 87.8%, respectively (Benalia et al., 2021). This difference can be explained by the soluble nature of the powder in water, where the liquid form of the coagulant is easily soluble and results in a better turbidity removal efficiency (Benalia et al., 2021).

Several factors may explain the different coagulation capacities of plant species. For example, the biochemical composition (protein content and type, starch, polyelectrolytes, lipids, and essential minerals) of plant species may differ and may or may not have a direct relationship with coagulation. Although there are contradictory reports on the active agentresponsible for coagulation, most scientists agree that polysaccharides and proteins are the two active coagulation agents in the seeds of vegetables and legumes (Yin, 2010). The presence of starch and protein in the *O. ficus indica* extracts was confirmed by proximate analysis; however, starch was found to be more abundant than protein. The combination of these chemical components in extracts may improve the ability of plant species to coagulate (Narasiah et al., 2002).

Variations in phytochemicals in plant species result in differences in their performance, which can affect the dose used. The optimal dose for the removal of turbidity at 33 ntu in the current investigation was 20 mg/L. According to a similar study, the optimal dose of *Opuntia* spp. in low-turbidity water is between 5 and 15 mg (Miller et al., 2008). 3 mL/200 mL was optimal for better removal of turbidity (Hadadi et al., 2022). With the optimal doses, WHO permissible drinking water concentrations <5NTU were achieved (WHO, 2006). However, a recent study on the efficacy of turbidity removal of *O. ficus-indica* revealed low coagulation activity (Konkobo et al., 2023). Turbidity removal can change depending on a number of factors, including crop year, soil composition, climatic type, regional features (Pritchard et al., 2009; Gunaratna et al., 2007) and raw water characteristics (Pritchard et al., 2016).

In addition to the biochemical components used, the properties of raw water also have a great impact on how well coagulation works (Pritchard et al., 2009). Somasundaran et al. (2005) and Usman et al. (2023) claims that pH can strongly affect the efficiency of the coagulation process as it influences the electrochemical nature of the ionic polymers and solvents utilized. Our study showed that a baseline pH of 8 was optimal for the removal of turbidity. In a related study, Miller et al. (2008) found that *Opuntia* had the maximum coagulation activity in basic water samples. In a similar study, *Opuntia* spp. was shown to work best with basic (pH 10) water samples and less well with acidic ones (Zhang et al., 2006; Bouaouine et al., 2018). Iqbal et al., 2016; Hadadi et al., 2022) reported pH 7 to 7.5 was the optimum for removing turbidity using *Opuntia microdasys* and *O. ficus-indica* powders. A recent study by Otalora et al. (2022) reported that coagulant from oat and onion performed better in basic water. However, other studies have shown that plant species perform better in acidic water. For instance, Benalia et al. (2021) reported that extracts of *A. vera* exhibited improved coagulation performance at pH 6. In a similar study, *Annona diversifolia* seed extract showed improved turbidity removal efficiency at pH 3, at an optimal dosage of 25 mg/L for water treatment (Usman et al., 2023). At an optimal pH of 4 and a desired dose of 6 mg/L, 82.80% of the turbidity was removed from the river water by banana pith (Zainol et al. 2023).

This discrepancy can be due to differences in the solubility of active coagulation agents and dominating surface charges (Choy et al., 2014). At a pH above 7, more negatively charged ions are present in kaolin suspensions, which enhances charge neutralization. On the contrary, at a pH lower than 7, the kaolin particles are less negatively charged, causing increased repulsion effects between polyelectrolytes and particles, thereby reducing the coagulation efficiency (Yin 2010). The coagulation efficiency also depends on the net surface charge of the coagulant. At lower pH values, the anionic components of the coagulant are responsible for the removal of turbidity (Hussain et al., 2019). For example, the charge in the extract of *A. diversifolia* was found to be negative and, during the coagulation and flocculation process, the added dose of *A. diversifolia* seed extract in the water destabilizes the negative surface of the particles (Usman et al., 2023). The anionic coagulant polymer is then attracted to the positive side of the destabilized particles and forms flocs (Koul et al. 2022). At higher pH values, the cationic components are more activated, enhancing the coagulation flocculation process (Hussain et al., 2019). This could also explain the improved turbidity removal efficiency of *O. ficus-indica* and other species in basic water.

Several studies have shown that solvents have an impact on the coagulation performance of plant-based coagulants. In the present study, coagulants extracted with 0.5 M NaCl had the highest removal efficiency. The removal efficiency of *O. ficus-indica* using 0.5 M NaCl was 91.6%, while the efficiency was 80% with deionized water. Previous research produced similar findings; Hadadi et al. (2022) reported that NaCl was more effective in extracting the active ingredient from *O. ficus-indica*. A comparison of the efficacy of coagulant aqueous and salt extracts of coagulants Gunaratna et al., (2007) and Sarpong et al., 2010) revealed that the overall efficacy of coagulation was significantly increased by salt extraction of powdered *M. oleifera* seeds than by extraction of water. The turbidity removal efficiency of *Jatropha curcas* was enhanced by NaCl solution, as indicated by Abidin et al. (2013). The authors indicated that with 50 ntu turbidity, using 0.5 M NaCl, the percentage of turbidity removal was approximately 96.8% compared to that of distilled water extraction. Plant species have better coagulation efficiency because salting improves the solubility of coagulant proteins (Okuda et al., 1999). Protein solubility in salt solution increased as a result of the superior performance of NaCl solution compared to pure water as a solvent to dissolve protein, protein polysaccharides, and other substances in powdered seeds (Hadadi et al., 2022).

In addition to extracting solvents, the choice of a particular method for extracting coagulating active components also influences the quantification of the active content of a plant species (Onyutha and Auma, 2023). However, extraction processes differ for each type of natural coagulant (Ang et al., 2020). Factors that can influence protein extraction also include maceration and extraction time (Onyutha and Auma, 2023; Megersa et al., 2917; Akyuz and Ersus, 2021). For example, the optimal extraction time using a magnetic stirrer for the seed powder from *M. stenopetala* was 15 min, while that of the *M. subcordata* tubers was 30 min (Megersa et al., 2017). Increasing the maceration time leads to a decrease in the amount of protein extracted from the leaves of oak plants where the maximum number of proteins was obtained after 4 h of maceration (Benalia et al., 2023). A decrease in turbidity removal efficiency was observed as a function of increased extraction time (Megersa et al., 2017), which could be due to the extraction of lipids and phenolic compounds, which can subsequently prevent the isolation of proteins that hinder the coagulation and flocculation processes (Megersa et al., 2017; Benalia et al., 2023). Adjeroud-Abdellatif et al. (2022) extracted mucilage from *O. ficus-indica* was extracted by conventional extraction and ultrasound-assisted extraction, where ultrasound-assisted extraction improved the yield of mucilage extraction. After 10 min, the extraction yield reached 61%, while after 60 min the conventional extraction yield was only 37%. However, when the conventional extraction method was compared to the ultrasound extraction method, a comparable protein content and turbidity removal efficiency were found when the seeds of *J. curcas* were extracted, although the extraction process took longer (Abidin et al., 2013). Furthermore, the use of ultrasound may incur additional operational costs in terms of energy consumption and power consumption (Abidin et al., 2013).

When *O. ficus-indica* extracts were added to the treated water, the initial pH changed somewhat, but the alum treatment resulted in a considerable decrease in pH. Several researchers have reported similar results using *O. ficus-indica* as a coagulant (Zhang et al., 2006; Hadadi et al., 2022). In addition to the plants in the present study, the other plant species did not significantly change the pH of the treated water. For instance, *A. vera* (Benalia et al., 2021); banana, banana peel (Azamzam et al., 2022; Kalibbala et al., 2023); cassava (Lugo-Arias et al., 2020) showed slight variations in the pH of the treated water compared to that of alum, where the water became acidic. Due to the increased investment required to fix it, this is a serious issue for treatment plants. A pH ranging from 6.5 to 8.5 is the recommended range for drinking water (WHO, 2006).

Recent findings have indicated that the use of *M. indica* seeds can reduce or increase pH according to the chemical nature of the substance, contributing to the turbidity of polluted water (Onyutha and Auma, 2023). The organic composition of the biocoagulant may have contributed to this result (Benalia et al., 2019). As mentioned in the literature, the activity of *O. ficus-indica* is due to the long chains of polysaccharides, which are primarily responsible for coagulation through bridging and adsorption mechanisms (Miller et al., 2008; Adjeroud-Abdellatif et al., 2022). Electrolytes of *Opuntia* spp., especially divalent cations, can facilitate this process (Miller et al., 2008; Adjeroud-Abdellatif et al., 2022). Approximately 20% of the charged sugars in mucilage can interact with ionic species (Majdoub et al., 2001). The slight increase in the pH of the water treated with *O. ficus-indica* could be explained by the release of hydroxyl groups into the water (Amagloh et al., 2009). In contrast, metal-based coagulants hydrolyze in water and release H^+ ions, resulting in a decrease in pH (Benalia et al., 2021).

5. Conclusions and recommendations

The finding of the study indicated *O. ficus-indica* is effective in treating surface turbid water. The dosage of coagulant, extraction solvent, and pH affect the effectiveness of *O. ficus-indica* turbidity removal in water treatment. At the optimal NaCl concentration of 0.5 M, using an optimal dose of 20 mg/L *O. ficus-indica,* the efficiency of turbidity removal was 85% at 33 ntu. Using an optimal dose of 40 mg/L at 60 ntu and 100 ntu, the turbidity removal efficiencies were 91.6% and 95%, respectively. Considering the environmental and health effects of alum, this plant can be used as an alternative source for water purification. However, repeating toxicological studies is prudent before the results are made available to end users. In conclusion, a key component of environmental sustainability in water treatment could be the use of plant-derived biocoagulants.

Acknowledgments

The authors thank JIJE laboglass (Addis Ababa) for their support in laboratory analysis (proximate). We also express our gratitude to the Research, Community Service, and Technology Transfer Office of Madda Walabu University for financial support.

Authors' Contributions

MM perceived the idea of the study. MM, BA, AA and HT carried out plant specimen collection and water sample collection. MM, JA HT and GD conducted the experiments. BA AA and BK performed the data analysis. MM participated in the writing of the manuscript. BA, AA, HT, BK and GD reviewed and finalized the manuscript. All authors read and approved the final manuscript.

Data availability statement

The data can be obtained from the corresponding author on request.

Declaration of competing interest

The authors declare no competing interests.

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