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Green Approach for Water Treatment

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To cite this article:

Ng, K., Alston, S., Castro, S., & Santiago, E. (2024). Green approach for water treatment. *International Journal on Engineering, Science, and Technology (IJonEST), 6*(1), 89-99. https://doi.org/10.46328/ijonest.197

International Journal on Engineering, Science, and Technology
2024, Vol. 6, No. 1, 89-99 https://doi.org/10.46328/ijonest.197

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Article Info

Article History

Received:
05 April 2023
Accepted:
11 November 2023

Keywords

Water
Coagulation
Turbidity
Seed
Avocado

Abstract

The common first step for water treatment is removing the particulate impurities by coagulation and flocculation. The conventional treatment uses polyvalent salts such as aluminum sulfate, iron (III) chloride, and synthetic polymers as coagulating agents which leads to potential toxicity. The purpose of this study is to identify environmentally friendly natural products as coagulant agents for water treatment. Four plant seeds (Amaranth, chia, quinoa, and wheat germ), corn cob, orange peel, and avocado peel were tested. Turbidity measurements were conducted with a wireless, portable turbidity sensor. Data was collected on a smartphone. The performance of the turbidity sensor was evaluated by preparation of a calibration curve (r^2 = 0.9928). Results show that all four plant seeds and avocado peel demonstrated the ability to decrease the turbidity of the water sample. Among the four seeds that were studied, Amaranth and chia were identified as the top two natural coagulant agents. Inter-day and Intra-day studies were performed for the turbidity measurements. The relative standard deviation (RSD) was found to be less than 10%, indicating the method has good precision. The method can serve as a point-of-use water treatment in remote areas of developing countries with limited resources.

Introduction

Access to clean water and accessible water purification has become a crucial issue affecting the world. It is expected that our water shortage will continue to increase. As a way of addressing this issue, research is being done to develop new procedures and techniques. While chemicals are commonly used for water purification, a green approach with the use of natural resources has been explored. The green approach has the potential to provide an environmentally friendly, reliable, and energy-efficient method for water purification (Grini, 2019). The use of natural resources for water treatment is particularly essential for remote areas of third-world countries where costly water treatment facilities and trained technical personnel may not be available.

A common first step for water treatment is clarification by coagulation and flocculation of colloids and particulate impurities (Jiang, 2015, Manhokwe, 2019). Colloids and particulate matter are destabilized by the added coagulants. This process is followed by flocculation, in which the coagulated particles aggregate together to form larger flocs that can be removed easily. Coagulation and flocculation are commonly used as interchangeable terms." Natural coagulants are sustainable, environmentally friendly, inexpensive, and simple to use. Unlike conventional chemical coagulants, the performance of natural coagulants is independent of the pH of the water being treated and is safe for humans.

Turbidity is an important measure of water quality. The “Cloudiness” of water due to the presence of suspended and colloidal matters is referred to as turbidity (Grobbelaar, 2009). Visibility or clarity decreases as the turbidity increases in each water body. Construction, mining, agriculture, and stormwater run-off after rainfalls that wash off sediments from urbanized areas and farmland can lead to an increase in water turbidity (Zhang, 2020). Water turbidity affects the growth of submerged aquatic plants. Suspended particles in water with high turbidity absorb heat from sunlight and lead to temperature increases in water. In addition, suspended particles scatter sunlight and minimize photosynthesis activity in deeper water. Submerged aquatic plants provide food, shelter, and protection for many different aquatic invertebrate and vertebrate species. Declines in this habitat will indirectly affect populations of species that depend on it (Phan, 2022). Besides ecological impact, water turbidity impacts the suitability of water bodies for recreational activities such as swimming, fishing, and boating (Vesterinen, 2010). Turbid water that contains suspended solids may clog or cause excessive wear to pipes and machinery in manufacturing plants. Turbid water may also clog filters, tubing, and emitters. Consequently, turbid water may not be suitable for agricultural micro-sprinkler irrigation and microfiltration for drinking water (Choi, 2010). Excessive turbidity may decrease the efficiency of herbicides used for aquatic weed control due to sorption (Lozano, 2019). Most importantly, viruses, bacteria, and contaminants such as pesticides, metals and toxic organic compounds can attach to suspended particles in turbid taps and drinking water (Gómez-Couso, 2009). Turbidity in drinking water provides shelter and nourishment for pathogens that can cause waterborne disease outbreaks. Many waterborne diseases can cause significant gastrointestinal illnesses with symptoms such as headaches, stomach cramps, diarrhea, nausea, and vomiting (Gaffield, 2003).

As indicated above, turbidity is an important parameter to assess water quality. The World Health Organization suggested less than 1 nephelometric turbidity unit (NTU) for drinking water (World Health Organization, 2022). The US Environmental Protection Agency (EPA) also sets the maximum level of turbidity in drinking water at 1 NTU (Environmental Protection Agency, 2012). It is essential to reduce water turbidity to ensure the safety of drinking water, decrease ecological impact, prolong filtration and irrigation systems’ lifespan, etc.

Conventional water treatment uses aluminum and iron salts as coagulants (Duan, 2003). However, ingested aluminum is toxic to humans and causes neurological diseases such as Alzheimer's (Niquette, 2004). One of the natural resources that has been commonly used for water treatment is chitosan (also known as chitin). Chitosan is a marine-derived sugar that can be collected from the outer skeleton of shellfish as well as crab, lobster, and shrimp. Chitosan can act as a coagulant in high-turbid bodies of water (Kenz, 2019; Soros, 2019). Chitosan is also a useful recyclable flocculation agent (Xu, 2021). Another natural coagulant that has been used for water treatment is the drought-resistant moringa seeds (Yogeshkumar, 2013). Water treatment with Moringa oleifera (MO) seed is not harmful to humans and has no notable drawbacks (Alo, 2012; Bina 2010; Eman, 2014; Shan, 2017). The purpose of this project is to identify plant seeds and other natural resources as coagulant candidates for water treatment and evaluate the performance of a wireless portable turbidity sensor. The effect of chitosan (if any) on the coagulating ability of plant seeds was also investigated with a preliminary study.

Experimental

Material and Instrumentation

The wireless turbidity sensor (Model: PS-3215) was from Pasco Scientific (Roseville, CA, U.S.A.) Data was collected wirelessly on a smartphone with the SPARKvue app. Turbidity calibration standard (100 NTU) was purchased from Sigma-Aldrich (St. Louis, MO, U.S.A.) Chitosan powder was purchased from Bulk Supplements (Henderson, NV). Amaranth seed, chia seed, quinoa seed, wheatgerm, fresh corn, avocados, and oranges were purchased from local stores (Norco, CA). Dirt, wastewater from the carwash runoff, and water from irrigation were collected from local residencies.

Evaluate the Performance of Wireless Portable Turbidity Sensor

Six standard solutions (turbidity value range from 100.0-3.1 NTU) were prepared from the 100 NTU turbidity calibration standard and the corresponding turbidity values were measured. Results are shown in Figure 1.

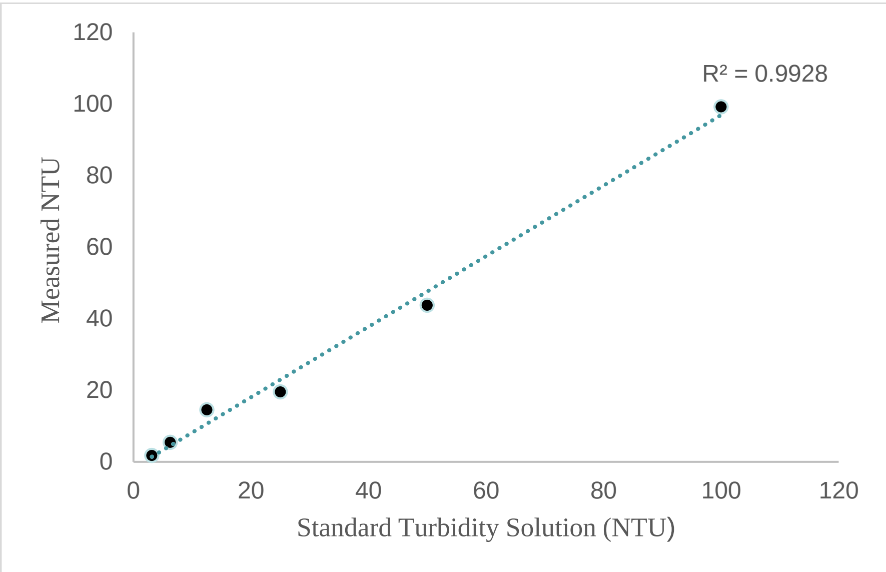

Figure 1 Calibration of the Wireless Portable Turbidity Sensor

Study of the Effectiveness of Plant Seeds on Water Treatment

Preparation of Dirty Water Sample

10 grams of dirt was collected. The dirt was sifted with a sifter to remove rocks, twigs, etc. The sifted dirt was ground with a mortar and pestle. A dirty water sample was prepared by weighing 0.50 grams of the ground dirt into a beaker containing 50 mL of distilled water.

Preparation of Flocculation Solutions

The plant seeds used for this study were chia, amaranth, quinoa, and wheat germ. Five grams of each seed was ground using a mortar and pestle. The ground seeds were stored in plastic containers. 0.200 g of the ground seeds was added to a scintillation vial, followed by 20 mL of distilled water. For comparison purposes, the flocculation solution was made from chitosan powder by following the same procedure.

Treatment of Dirty Water by Flocculation Solutions

The dirty water sample was stirred and immediately transferred to a 3-mL cuvette. Initial turbidity reading was obtained after 10 minutes. One milliliter of the prepared flocculation solution was then added to the cuvette. The final turbidity reading was recorded after 10 minutes. Changes in turbidity were calculated from the final and initial turbidity values.

Intra-day and Inter-day Studies

Intra-day studies were performed by treating three dirty water samples with the prepared flocculation solutions on the same day. Inter-day studies were performed by treating three water samples on three different days. Results are shown in Table 1 and Table 2 respectively.

Table 1 Intra-day Studies for Treatment of Water Sample by Plant Seeds

	Change in turbidity reading in the treated dirty water sample (NTU)				
Flocculation solution	**Run 1**	**Run 2**	**Run 3**	**Average**	**Relative Standard Deviation (RSD)**
chitosan (for comparison)	-97.5	-86.4	-100.5	-94.8	7.84%
chia	-35.6	-34.0	-36.3	-35.3	3.34%
Amaranth	-25.7	-28.7	-29.7	-28.0	7.43%
wheat germ	-14.7	-12.5	-13.6	-13.6	8.09%
quinoa	-6.00	-7.10	-6.70	-6.60	8.44%

Table 2 Inter-day Studies for Treatment of Water Sample by Plant Seeds

	Change in turbidity reading in the treated dirty water sample (NTU)				
Flocculation solution	**Run 1**	**Run 2**	**Run 3**	**Average**	**Relative Standard Deviation (RSD)**
chitosan (for comparison)	-97.5	-100.8	-113.4	-103.9	8.08%
chia	-35.6	-34.7	-35.8	-35.4	1.66%

Amaranth	-25.7	-25.8	-27.0	-26.2	2.76%
wheat germ	-14.7	-12.1	-13.4	-13.4	9.70%
quinoa	-6.0	-7.1	-6.8	-6.6	8.57%

Application Study

The top two coagulant candidates from the intra-day and inter-day (chia seed and Amaranth seed) were used to treat real-life water samples. Wastewater from the carwash was treated with ground chia seed and Amaranth seed by using the procedures described above. For comparison purposes, chitosan powder was used to treat carwash wastewater with the same procedures. Results are shown in Table 3.

Table 3 Treatment of Carwash Wastewater by Plant Seeds

Flocculation solution	**Change in Turbidity Reading (NTU)**
Chitosan (for comparison)	-34.6
chia	-16.4
Amaranth	-4.9

Preliminary Investigation on the Ability of Chitosan to Enhance the Effectiveness of Plant Seeds for Water Treatment

Study the Effect of Chitosan on Plant Seeds

The dirty water sample was stirred and immediately transferred to a 3-mL cuvette. Initial turbidity reading was obtained after 10 minutes. 0.025g of ground seeds and 0.025 g of chitosan powder were added to the cuvette. The final turbidity reading was recorded after 10 minutes. Changes in turbidity were calculated from the final and initial turbidity values. For comparison purposes, the above procedures were conducted by using 0.050 g of chitosan powder. Changes in turbidity were calculated from the final and initial turbidity values, results are shown in Table 4.

Control Experiment

The dirty water sample was stirred and immediately transferred to a 3-mL cuvette. Initial turbidity reading was obtained after 10 minutes. 0.050g of ground seeds was added to the cuvette. The final turbidity reading was recorded after 10 minutes. Changes in turbidity were calculated from the final and initial turbidity values. For comparison purposes, the above procedures were conducted by using 0.050 g of chitosan powder. Changes in turbidity were calculated from the final and initial turbidity values, results are shown in Table 5.

Table 4 Treatment of Dirty Water by Combination of Plant Seeds and Chitosan

Treatment	**Initial Turbidity Reading (NTU)**	**Final Turbidity Reading (NTU)**	**Changes in Turbidity Reading**
chitosan (for comparison)	215.5	122.4	-93.1
chia + chitosan	253.6	214.2	-39.4
Amaranth + chitosan	292.8	261.5	-31.3
wheat germ + chitosan	281.7	225.2	-56.5
quinoa + chitosan	274.2	239.9	-34.3

Table 5 Treatment of Dirty Water by Plant Seeds Alone

Treatment	**Initial Turbidity Reading (NTU)**	**Final Turbidity Reading (NTU)**	**Changes in Turbidity Reading**
chitosan (for comparison)	183.2	84.7	-98.5
chia	538.1	480.6	-57.5
Amaranth	184.3	122.8	-61.5
wheat germ	164.9	116.2	-48.7
quinoa	142.3	136.7	-5.6

Study the Effectiveness of Corn Cob, Avocado Peel, and Orange Peel for Water Treatment

Avocado peel, orange peel, and corn cob were washed, and boiled in water for 5 minutes. They were dried under the sun for 24 hours. The dried corn cob, avocado peel, and orange peel were ground with a food processor and stored in the corresponding storage bottle.

Preparation of Flocculation Solutions

0.200 g of ground avocado peel, orange peel, or corn cob was added to a scintillation vial, followed by 20 mL of distilled water. For comparison purposes, the chitosan solution was prepared the same way by weighing 0.200 g of chitosan powder into a scintillation vial, followed by 20 mL of distilled water.

Treatment of Runoff Water from Irrigation by Flocculation Solutions

The collected runoff water from irrigation was stirred and immediately transferred to a 3-mL cuvette. Initial turbidity reading was obtained after 10 minutes. One milliliter of the prepared flocculation solution was then added to the cuvette. The final turbidity reading was recorded after two hours*. Changes in turbidity were calculated from the final and initial turbidity values. For comparison purposes, the above procedures were conducted with a flocculation solution prepared from chitosan powder.

*Note: Turbidity readings were recorded after 10 minutes, 1 hour, 2 hours and 12 hours. Water samples that were treated with corn cob and orange peel did not show any change in the turbidity readings after 12 hours. Water samples that were treated with avocado peel show the biggest decreases in turbidity reading after 2 hours. Thus, it was decided to record the final turbidity value after 2 hours of the addition of the flocculation solutions.

Intra-day and Inter-day Studies

Intra-day and Inter-day studies were performed by treating water samples with the flocculation solutions prepared with avocado peels. Intra-day studies were performed by treating three dirty water samples on the same day. Inter-day studies were performed by treating three water samples on three different days. Results are shown in Table 6 and Table 7 respectively.

Table 6 Intra-day Studies for Treatment of Runoff Water from Irrigation by Avocado Peel

	Change in turbidity Reading (NTU)				
Flocculation solution	**Run 1**	**Run 2**	**Run 3**	**Average**	**Relative Standard Deviation RSD**
chitosan (for comparison)	-23.1	-20.6	-22.3	-22.00	5.80%
avocado peel	-15.3	-17.5	-17.6	-16.8	7.64%

Table 7 Inter-day Studies for Treatment of Runoff Water from Irrigation by Avocado Peel

	Change in turbidity Reading (NTU)				
Flocculation Solution	**Run 1**	**Run 2**	**Run 3**	**Average**	**Relative Standard Deviation RSD**
chitosan (for comparison)	-23.1	-24.8	-24.3	-24.1	3.63%
avocado peel	-15.3	-16.4	-16.4	-16.0	3.91%

Discussion and Conclusions

Evaluate the Performance of Wireless Portable Turbidity Sensor

The calibration curve shows an excellent relationship between the turbidity reading from the wireless, portable turbidity sensor and the standard solutions (r^2 value =0.9928). This indicates that the turbidity sensor provides accurate readings. Data was collected conveniently on a smartphone via the SPARKvue app.

Study of the Effectiveness of Different Seeds on Water Treatment

As shown in Table 1 and Table 2, turbidity values of the dirty water sample decreased after the treatment of plant seeds. This shows that all four plant seeds can be used as coagulant agents for water treatment. The water sample treated with chia seeds shows the highest decrease in turbidity followed by Amaranth seed. This indicates that the top two candidates of coagulate agents for water treatment are chia seed and Amaranth seed. Results from intra-day and inter-day studies show that the proposed method has good precision (relative standard deviation <10%). For comparison purposes, the water sample was treated with chitosan (a known natural coagulant agent) by using the same procedures. Results show that chitosan is more effective than all four plant seeds that were tested in this study. Wastewater from carwash was treated with the top two identified coagulate agents (chia seed and Amaranth seed) and chitosan (for comparison purposes). Results show that both the chia seed and Amaranth seed are effective in decreasing the turbidity of the carwash water (see Table 3).

Preliminary Investigation on the Ability of Chitosan to Enhance the Effectiveness of Seeds for Water Treatment

As shown in the data from Table 4 and Table 5, turbidity reading for the treated water sample decreased to a larger extent when chitosan powder was used together with the quinoa seed than when quinoa seed was used alone. A similar result was seen for wheat germs. On the other hand, turbidity reading for the treated water sample decreased to a smaller extent when chitosan powder was used together with Amaranth seed than when Amaranth seed was used alone. A similar result was seen for the chia seed. No conclusion can be drawn on whether chitosan is enhancing the coagulating properties of the plant seeds from the study. Further experiments will have to be conducted to investigate this matter.

Study the Effectiveness of Corn Cob, Avocado peel, and Orange peel for Water Treatment

Water samples (runoff water from irrigation) that were treated by the orange peel and corn cob did not show any change in the turbidity readings after twelve hours. Water samples that were treated with the avocado peel show the biggest decreases in turbidity reading after 2 hours. For comparison purposes, water samples were treated with chitosan by following the same procedures. Results show that chitosan is a more effective coagulant agent than avocado peel. Results from the intra-day and inter-day studies (Table 6 and Table 7) show that the proposed water treatment method with avocado peel has good precision (relative standard deviation < 8.0%).

Overall Conclusions

Chia seeds and Amaranth seeds were identified as natural coagulant agents for water treatment. In addition, a new category of natural resources (fresh produce) was explored as potential coagulant agents for water treatment. It was found that avocado peel is a promising candidate to serve as coagulant agent for water treatment. It was demonstrated that reliable turbidity reading can be conveniently obtained from the wireless, portable turbidity sensor via a smartphone. The method used for this study shows good precision. The natural coagulant agents identified in this study are environmentally friendly, biodegradable, and sustainable. The method used in this study is user-friendly and can easily be implemented in a remote site with limited resources. The use of natural resources as coagulant agents can serve as a point-of-use (POU) water treatment method.

Acknowledgments

This project was funded by the "Campus as a Living Lab" grant from the Chancellor's Office of California State University.

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