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Environmentally-Friendly Bio-Coagulants: A Cost-Effective Solution for Groundwater Pollution Treatment

Venkatesan Govindaraj*, Kalpana Manokaran, Jegadeesh Sathaiya[1] and Praveen Baskar[2]

Department of Civil Engineering, Saveetha Engineering College, Chennai – 602 105, India
[1]Department of Artificial Intelligence and Data Science, Saveetha Engineering College, Chennai – 602 105, India
[2]Department of Computer Science (Cyber Security), Saveetha Engineering College, Chennai – 602 105, India
✉ gvenkatesan@saveetha.ac.in

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Abstract: Groundwater in aquifers is one of the most significant renewable natural resources. It provides drinking water to more than 90% of the rural population. The majority of domestic and industrial garbage is disposed off in open dumping yards. As a result, groundwater becomes contaminated and of poor quality. Many therapy strategies are being used in various regions of the world to address this issue. We investigated the groundwater properties in a section of an industrial city in southern India and treated the contaminated groundwater using natural bio-coagulants in this study. *Artocarpus heterophyllus* (Jackfruit peel), *Momordica charantia* (Bitter gourd seed), *Musa paradisiaca* (Banana blossom leaf), and *Cynodon dactylon* were employed as eco-friendly bio-coagulants (Scutch grass). These coagulants are good at removing turbidity while also keeping the pH of the water stable. Furthermore, these natural coagulants lower BOD, COD, and salt levels. Groundwater can be utilised for home purposes after treatment. Because it is a low-cost and environmentally friendly approach, a vast population can afford it.

Key words: Groundwater treatment, coagulation process, bio-coagulants, cost-effective method.

Introduction

Water is a crucial resource for all living beings. In our regular lifestyle, we utilise water for everything. Human activity has now poisoned the water. To utilise water, contaminated water must be treated. This is a brief description of how cost-effective treatment with bio-coagulants works. Groundwater hydrochemistry can be influenced by a variety of variables, including chemical reactions between water and soil or sediment, biological processes, surface water groundwater interactions, and human activities. Water pollution is a global problem that has had negative environmental and human health repercussions (Venkatesan et al., 2016; Venkatesan et al., 2020b; Venkatesan et al., 2022). Wastewater deposition has grown at an alarming rate as a result of fast industrialisation and population growth, impacting water quality. This has resulted in a variety of water treatment approaches for improving water quality (Sivakumar et al., 2014; Venkatesan et al., 2014). As a result, there is a lot of emphasis on enhancing and applying natural coagulants in wastewater treatment these days (Venkatesan et al., 2020c; Venkatesan et al., 2023a). Natural coagulants can be produced or extracted

*Corresponding Author

by animals, microorganisms, and plants (Natarajan et al., 2018; Venkatesan et al., 2018; Venkatesan et al., 2016b). Dolichas lablab, *Azadirachta indica*, Moringa oeifera, and *Hibiscus rosa sinensis* were the natural coagulants used in this study, and they are all accessible locally from vegetables and flowers (Venkatesan et al., 2019). Bio-flocculants are low-cost and renewable in nature with a large capacity for the removal of suspended solids, turbidity, and colours, reducing the impact on public health and pollution.

Materials and Methods

Figure 1 depicts the methodology flowchart for the current experiment. A groundwater sample was obtained near the Vellalore dumping grounds in the Tamil Nadu district of Coimbatore (Figure 2) (Aishwarya et al., 2014a; Venkatesan et al., 2016a). Vellalore, a village near Coimbatore with a Coimbatore Corporation garbage yard, is in the Coimbatore District's Kinathukadavu constituency. As a result of the garbage, the soil in this area erodes (Aishwarya et al., 2014b). The improper disposal of 850 tonnes of waste in the yard of 650 acres of property in and around the Vellalore region has poisoned groundwater. The improper disposal of 850 tonnes of waste in the yard of 650 acres of property in and around the Vellalore region has poisoned groundwater. For this investigation, we collected groundwater samples from roughly 1.5 kilometers distant from the Vellalore dumping site (Figure 3). Initial tests were performed to determine pH, electrical conductivity, calcium, magnesium, sodium, and potassium contents, as well as carbonate and bicarbonate, chloride, and TDS contents. Table 1 summarises the findings. *Artocarpus heterophyllus* (Jackfruit peel), *Momordica charantia* (Bitter gourd seed), *Musa paradisiaca* (Banana flower leaf), and *Cynodon dactylon* (Scutch grass) were obtained from a nearby market in Coimbatore. The chemical coagulant (alum) was collected and employed immediately in the form of a fine, white powder.

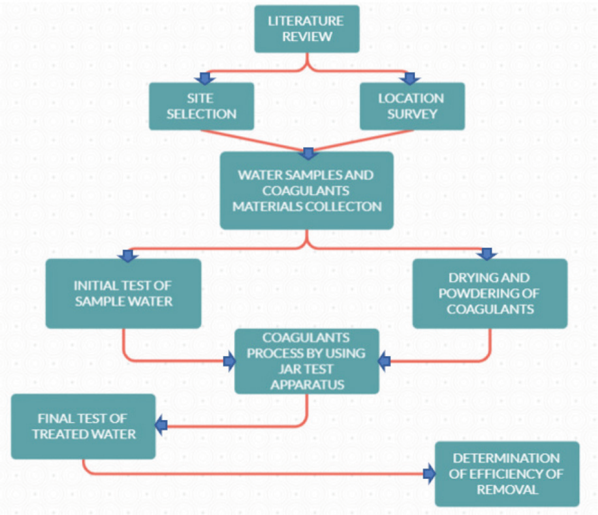

Figure 1: Methodology flowchart of study.

Preparation of Natural Coagulants

Coagulants were created by drying, powdering, and sieving the seeds and blossoms of various plants. After drying, the coagulants were ground into a fine powder. The powdered sample was sieved using 0.45mm mesh IS Sieves and stored in an airtight container to prevent moisture from entering and causing damage. The fine powder was used as a coagulant for analysis. Distilled water was used to make a 1% suspension of the powdered seed. The seed was then vigorously shaken for 45 minutes to improve the water's ability to absorb coagulant proteins before passing through filter paper.

Figure 2: Vellore dumping yard.

Figure 3: Groundwater sample.

Table 1: The initial characteristics result

S. No.	*Name of the parameter*	*Initial characteristics*
1	pH	7.38
2	Turbidity (NTU)	356
3	Electrical conductivity (S/m)	4.38
4	Calcium (mg/L)	7.28
5	Magnesium (mg/L)	7.92
6	Sodium (mg/L)	6.8260
7	Potassium (mg/L)	1.1794
8	Carbonate (mg/L)	-
9	Bicarbonate (mg/L)	0.88
10	Chloride (mg/L)	2.0
11	Sodium adsorption ratio	2.470
12	Res. sodium carbonate (mg/L)	14.32
13	Total dissolved solids (mg/L)	2803.2
14	COD (mg/L)	61.2
15	BOD (mg/lit)	88.7

Coagulation Process – Jar Test Analysis

The most often utilised procedures for eliminating turbidity, colour, suspended debris, germs, and other odour-causing materials are coagulation and flocculation (Venkatesan et al., 2020a). A classic laboratory experiment for evaluating the ideal operating conditions for water or wastewater treatment is the jar test. This approach simulates the operation of a large-scale treatment operation by allowing pH adjustments, modifications in coagulant or polymer dosage, alternate mixing speeds, or testing of other coagulant or polymer kinds.

Experimental Procedure

The coagulation-sedimentation analyses were carried out with the aid of a standard Jar test apparatus (Figure 13). In this study, five coagulants were used as a powder (Figure 8). As four naturally occurring coagulants, alum (Figure 9), banana flower leaf (Figure 4), bitter gourd seed (Figure 5), jackfruit peel (Figure 7), and scutch grass (Figure 6) were used, along with one chemical.

Figure 4: Banana flower coagulant powder.

Figure 5: Bitter gourd seed coagulant powder.

Figure 6: Scutch gras coagulant powder.

Figure 7: Jacfruit peel coagulant powder.

The powder was fed to the relevant samples at various doses of these natural coagulants, including 2 g, 4 g, 6 g, 8 g, 10 g, and 12 g (Figures 10-12). It was done in batches of six beakers and steel paddles with six spindles. The groundwater and bio-coagulant samples were completely mixed before being divided into 500 mL beakers. After 2 minutes of vigorous stirring at 100 rpm, 25 minutes of slow mixing at 20 rpm were managed to complete. The properties of the obtained supernatant (pH, turbidity, conductivity, and TDS) were evaluated after filtering. The methodologies used for analysing jackfruit peel, bitter gourd seed, banana flower leaf, and scutch grass were all similar to those described above. In the case of alum, it was ground into a fine powder and then used right away (Venkatesan et al., 2012). The test was carried out at room temperature (250°C). To assess the residual coagulants, 50 ml of sample was taken from the top 2 cm of the water surface and filtered through a filter paper after each experiment. Table 2 summarises the test reports (pH, turbidity, conductivity, and TDS content) on the cleaned-up polluted water.

Results and Discussion

In accordance with the findings of our investigation, the groundwater in the vicinity of the Vellalore Disposal site is polluted. Coagulation and flocculation are the principal and cost-effective processes in wastewater treatment facilities that may successfully reduce turbidity in water ranging from low to high turbidity when operating conditions are optimum. pH and coagulant dosage optimisation may improve coagulation performance while decreasing sludge volume and, consequently, sludge treatment costs. According to the findings, natural coagulants can be utilised to clean up unclean wastewater. The initial groundwater parameters, such as pH, electrical conductivity, calcium, magnesium, sodium, potassium, chloride, total dissolved solids, BOD, and COD were assessed (Karunanidhi et al., 2021). Figures 14 and 15 show the results, as does Table 1. Table 2 summarises the results of the Jar test with coagulant materials with a variety of various doses by adjusting the coagulant dosage as 2 g, 4 g, 6 g, 8 g, 10 g, and 12 g, the best coagulant dose for groundwater was identified. According to the data, the most efficient dose of coagulant for cleaning up groundwater pollution is 8 g.

Reduction of pH – Different Coagulant Dosages

The pH of any solution impacts the geochemistry of the coagulant during the flocculation process. The pH level fall after coagulant treatment of groundwater with an initial pH value of 7.38 is shown in Figure 16a at an

Figure 8: Powdered form of natural biocoagulant.

Figure 9: Alum-a chemical coagulant.

Figure 10: Different dosage of alum solution.

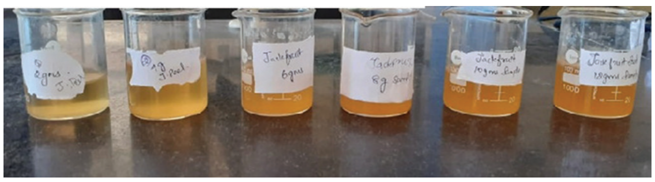

Figure 11: Jackfruit peel solution at different dosages.

Figure 12: Bitter gourd seed solution at different dosages.

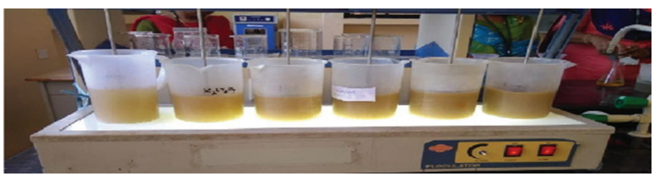

Figure 13: Jar test apparatus.

Table 2: Characteristics of treated water

Table 2.1: pH table for treated water for different coagulant dosages

Dosage of Coagulant	*pH for different coagulant material*				
	Alum	*Jackfruit peel*	*Banana flower leaf*	*Bitter gourd seed*	*Scutch grass*
2g	4.91	5.5	5.58	5.90	5.92
4g	4.77	5.33	5.20	5.80	5.82
6g	5.70	5.60	5.09	5.71	5.82
8g	6.64	5.90	6.09	6.54	6.69
10g	6.56	5.36	5.94	5.61	5.55
12g	7.46	5.52	5.53	6.46	6.50

Table 2.2: Turbidity table for treated water for different coagulant dosages

Dosage of coagulant	*Turbidity of coagulant material (NTU)*				
	Alum	*Jackfruit peel*	*Banana flower leaf*	*Bitter gourd seed*	*Scutch grass*
2g	67	126	146	134	138
4g	71	122	103	229	145
6g	66	450	153	460	216
8g	60	157	127	165	265
10g	59	608	155	601	392
12g	68	996	237	380	390

Table 2.3: Electrical conductivity table for treated water for different coagulant dosage

Dosage of coagulant	*Electrical conductivity of coagulant material (S/m)*				
	Alum	*Jackfruit peel*	*Banana flower leaf*	*Bitter gourd seed*	*Scutch grass*
2g	4.7	3.91	2.60	4.31	3.91
4g	5.7	3.95	2.86	4.30	4.24
6g	5.6	4.11	3.02	4.30	4.57
8g	4.2	4.01	2.77	4.10	3.87
10g	6.50	4.25	3.43	4.36	4.84
12g	7.16	4.34	3.50	4.39	4.92

Table 2.4: TDS table for treated water for different coagulant dosage

Dosage of coagulant	*TDS for different coagulant materials (mg/L)*				
	Alum	*Jackfruit peel*	*Banana flower leaf*	*Bitter gourd seed*	*Scutch grass*
2g	800	870	980	520	820
4g	810	800	870	500	810
6g	708	660	650	450	800
8g	650	560	780	370	790
10g	700	610	780	390	800
12g	730	730	800	430	1000

initial concentration of 2 g. The pH values for common alum and natural coagulant compounds are shown in the graph. Alum eliminated pH with a 33.47% efficiency. The pH level is falling with the 4 g coagulant dosage, as seen in Figure 16b. The pH values for conventional alum and natural coagulant materials are shown in the graph. The pH elimination effectiveness of alum was 35.37%. The pH level decline with a 6 g coagulant dosage is depicted in Figure 16c. The pH level fall with an 8g coagulant dosage is indicated in Figure 16d. The graph displays the pH values for natural coagulant chemicals as well as a standard alum as a coagulant, which resulted in a removal efficiency of 20.01 percent in jackfruit peel. Figure 16e depicts the pH level drop at 10 g coagulant dosage. The graph displays the pH values for typical alum and natural coagulant components, with jackfruit peel attaining a 27.37 percent pH removal efficacy. The pH level drop at a 12 g coagulant dosage can be seen in Figure 16f.

Reduction of Turbidity – Different Coagulant Dosages

The decrease in turbidity at the 2 g coagulant dose is seen in Figure 17a. Turbidity levels for artificial and natural coagulants are displayed in the graph. Alum's turbidity clearance efficiency was found to be 81.18%. Figure 17b depicts the decrease in turbidity at the 4 g coagulant dosage. Turbidity readings for traditional alum and natural coagulant ingredients are displayed in the graph. Turbidity reduction efficacy of alum was 80.06%. The decline in turbidity at the 6 g coagulant dose is seen in Figure 17c. Figure 17d depicts the decrease in turbidity at the 8 g coagulant dosage. Turbidity values for artificial and natural coagulants are shown in the graph. Alum's turbidity reduction effectiveness was found to be 83.15%. Figure 17e depicts the decrease in turbidity at 10 g coagulant dosage. Figure 17f depicts a decrease in turbidity with a coagulant dose of 12 g.

Reduction of Electrical Conductivity – Different Coagulant Dosages

At a coagulant dosage of 2 g, electrical conductivity is lessened in Figure 18a. The graph depicts the EC values for natural coagulants and conventional alum. The EC amputation efficiency of the banana flower leaf was 40.64%. At a 4g coagulant dose, electrical conductivity is amputated in Figure 18b. The graph shows the EC values for natural coagulants and conventional alum.

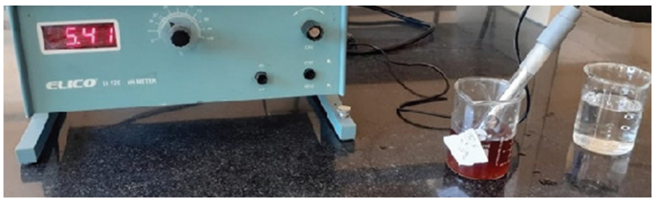

Figure 14: Testing of treated water-pH meter.

Figure 15: Testing of treated water-conductivity meter.

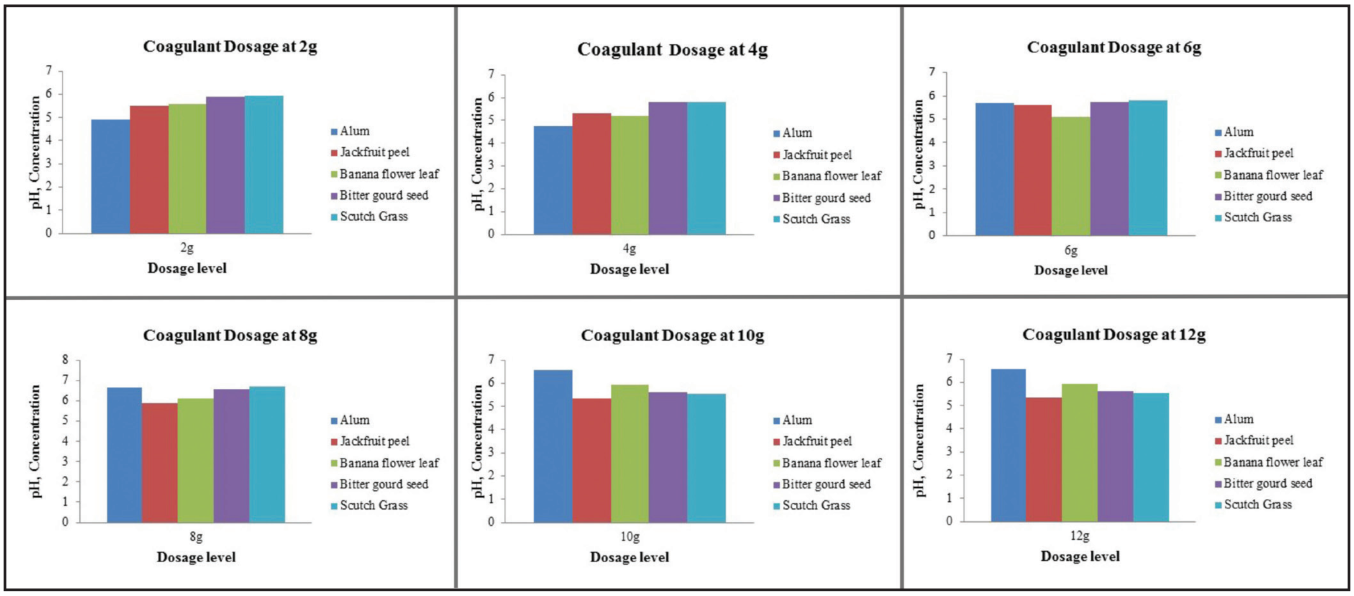

Figure 16: Reduction of pH – different coagulant dosages: (a) at 2 g, (b) at 4 g, (c) at 6 g, (d) at 8 g, (e) at 10 g and (f) at 12 g.

The effectiveness of EC elimination in banana flower leaves was 34.70%. At a coagulant dosage of 6 g, electrical conductivity is lowered in Figure 18c. The graph shows the EC values for natural coagulants and conventional alum. The elimination efficiency of EC in banana flower leaves was 31.05%. At an 8 g coagulant dosage, electrical conductivity is lowered in Figure 18d. As seen in Figure 18e, electrical conductivity diminishes with a 10 g coagulant dosage. At a coagulant dosage of 12 g, electrical conductivity is lessened in Figure 18f. The elimination efficiency of EC in banana flower leaves was 20.10%, in accordance with this graph.

Reduction of TDS – Different Coagulant Dosages

Figure 19a depicts the decline in TDS at the 2 g coagulant dosage. TDS values for conventional alum as a coagulant and natural coagulant materials are shown in the graph. This resulted in a TDS removal

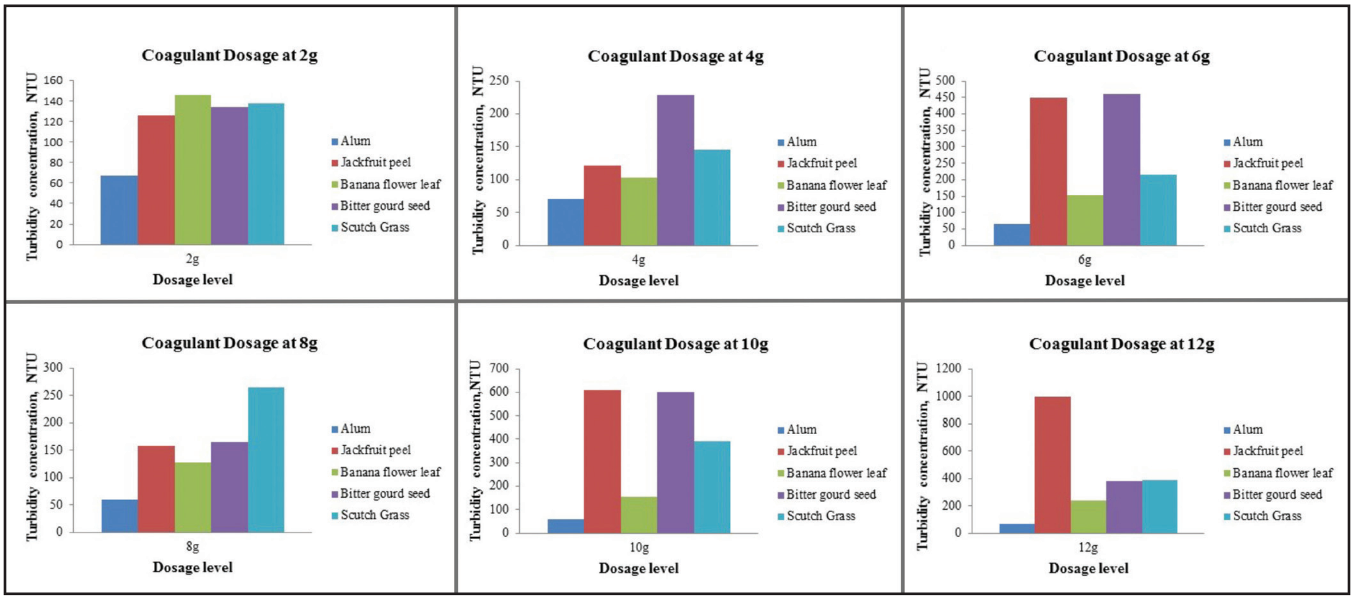

Figure 17: Reduction of Turbidity – different coagulant dosages: (a) at 2 g, (b) at 4 g, (c) at 6 g, (d) at 8 g, (e) at 10 g and (f) at 12 g.

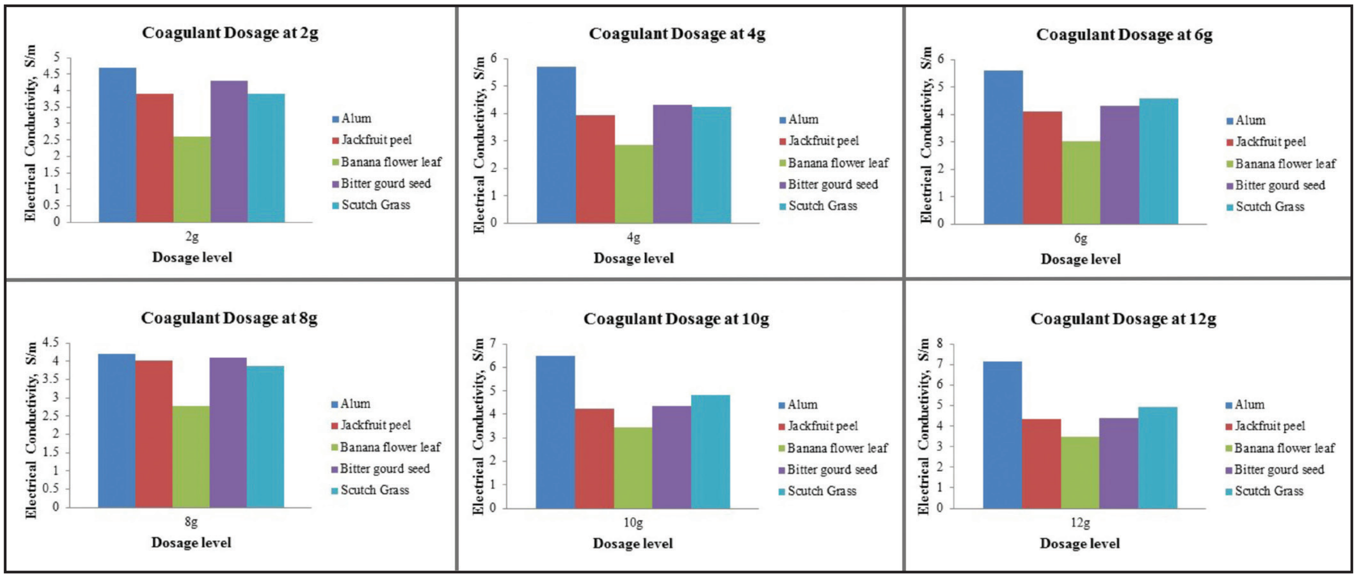

Figure 18: Reduction of EC – different coagulant dosages: (a) at 2 g, (b) at 4 g, (c) at 6 g, (d) at 8 g, (e) at 10 g and (f) at 12 g.

effectiveness of 81.45% in bitter gourd seed. Figure 19b depicts the decrease in TDS at the 4 g coagulant dosage. The graph shows the TDS readings for conventional alum and organic coagulants, which result in a TDS elimination efficiency of 82.16% in bitter gourd seed. Figure 19c depicts the decline in TDS at the 6 g coagulant dosage. TDS values for traditional alum and organic coagulants are shown in the graph. producing an 83.95% TDS removal efficiency in bitter gourd seed. Figure 19d shows the reduction in TDS at the 8 g coagulant dose. The graph represents the TDS values for natural coagulants and conventional alum as a coagulant, resulting in a TDS removal efficiency of 86.80% in bitter gourd seed. Figure 19e shows TDS decrease at 10 g coagulant dosage. The decline in TDS at the 12 g coagulant dose is seen in Figure 19f.

Alum as Coagulant Material

After alum treatments, the optimal coagulant dosage for contaminated groundwater was 4 g. The pH was reduced by 35.37%, and a pH range of 4.77 was found to be optimum. The optimal coagulant dosage of 10 g resulted in an 83.43% turbidity removal effectiveness, and the appropriate turbidity range was reported to be 59 NTU. At 8 g of the appropriate coagulant dosage value and elimination efficiency, the electrical conductivity of the treated groundwater was 4.11 percent, with the ideal alum value being 4.2 s/m. The removal effectiveness of TDS from groundwater during the post-treatment operation was 76.81% at 8 g of coagulant dose and an optimal value of 650 mg/L.

Jackfruit Peel as Coagulant Material

The best coagulant dose for treated water was discovered to be 4 g after treatment with jackfruit peel powder. The ideal pH value was discovered to be 5.33, with a pH clearance efficacy of 27.77%. The optimal coagulant dosage of 8 g resulted in a turbidity reduction effectiveness of 55.90% and a turbidity range of 157 NTU. The removal efficiency and electrical conductivity of treated groundwater were 10.73% and 3.91 s/m of alum, respectively, at 2 g of the optimal coagulant dose amount. The TDS of groundwater was eliminated with an efficiency of 80.02% during the post-treatment process using 8 g of coagulant dose and a 560 mg/L optimum value.

Banana Flower Leaf as Coagulant Material

Following banana flower leaf powder treatment, the optimal coagulant dosage for treated wastewater was 6 g. The optimal pH value was 5.09, and the efficacy of pH elimination was 31.03%. At 4 g of the optimum coagulant dose, the removal efficacy of turbidity was 71.07%, and the best turbidity range was determined to be 103 NTU. The removal efficiency and electrical conductivity of processed groundwater were 40.64% and 2.60 s/m of alum, respectively, at 2 g of the optimal coagulant dose amount. TDS removal effectiveness in the post-treatment process was 76.81% at a coagulant dosage of 6 g and an optimum value of 650 mg/L.

Bitter Gourd Seed as Coagulant Material

After the bitter gourd seed powder treatment, the

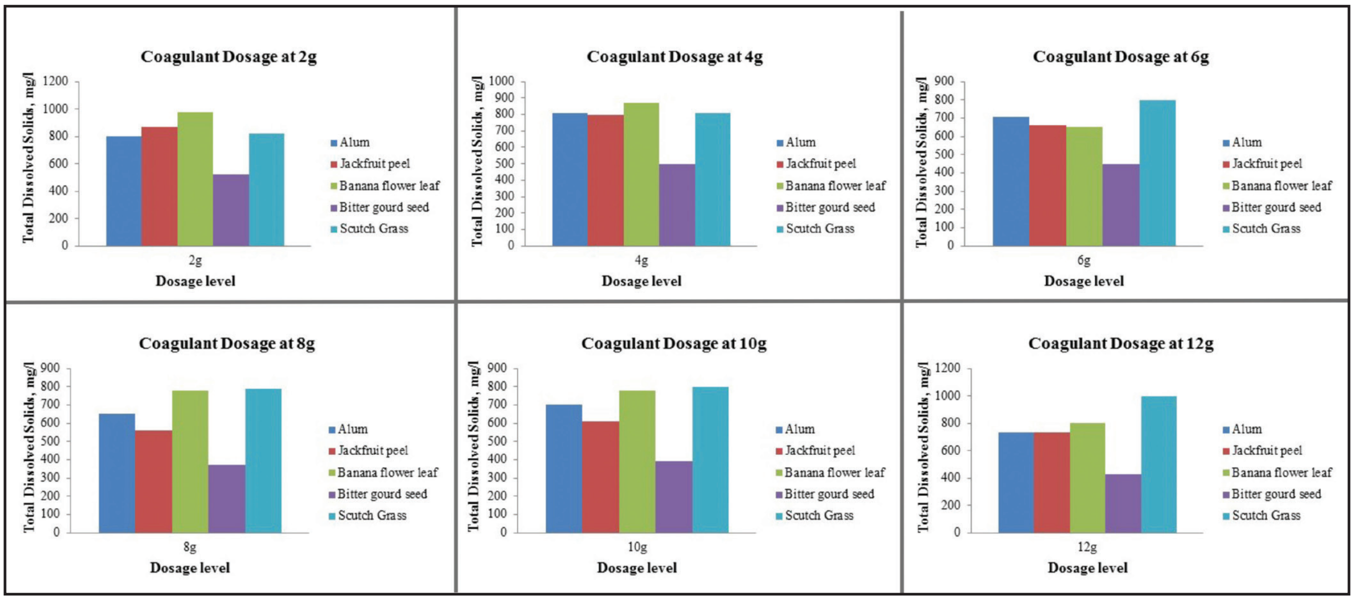

Figure 19: Reduction of TDS – different coagulant dosages: (a) at 2 g, (b) at 4 g, (c) at 6 g, (d) at 8 g, (e) at 10 g and (f) at 12 g.

optimal coagulant dosage for treated water was 10 g. The optimal pH level was 5.61, and the efficacy of pH elimination was 23.98%. The appropriate turbidity range was determined to be 134 NTU, and the optimal coagulant dosage of 2 g resulted in a clearance efficacy of a turbidity of 62.36%. The removal efficiency and electrical conductivity of treated groundwater were 6.39% and 4.10 s/m of alum, respectively, at 8 g of the optimal coagulant dose value. The elimination effectiveness of TDS from groundwater in the post-treatment process was 86.80% at 8 g of coagulant dosage with a maximum value of 370 mg/L.

Scutch Grass as Coagulant Material

The best coagulant dose for treated water after Scutch Grass powder treatment was 10 g. The optimal pH value was 5.55, and the efficacy of pH elimination was 24.80%. The optimal coagulant dosage of 2g resulted in a turbidity removal effectiveness of 61.24%, and the appropriate turbidity range was reported to be 138 NTU. At 2 g of the ideal coagulant dosage level, the removal efficiency and electrical conductivity of treated groundwater were 10.73% and 3.91 s/m of alum, respectively. At a coagulant dosage of 8 g and an optimum value of 790 mg/L, the removal effectiveness of TDS from groundwater during the post-treatment procedure was 71.82%.

Conclusions

Natural coagulants can be used to treat wastewater. In this analysis, the efficacy of total dissolved solids removal was evaluated between bio-flocculants and traditional chemical coagulants in terms of pH, turbidity, electrical conductivity, and pH under various process conditions. The use of an alum coagulant in groundwater decreases the proportion of different polluting properties such as pH, turbidity, electrical conductivity, and total dissolved solids. These decreases were 35.37%, 83.43%, 4.11%, and 76.81%, respectively. The jackfruit peel coagulant reduced pH, turbidity, electrical conductivity, and total dissolved solids percentages by 27.77%, 55.90%, 10.73%, and 80.02%, respectively. Banana flowers leaf coagulant reduced pH, turbidity, electrical conductivity, and total dissolved solids by 31.03%, 71.07%, 40.64%, and 76.81%, respectively. Bitter gourd seed coagulant reduced pH, turbidity, electrical conductivity, and total dissolved solids percentages by 23.98%, 62.36%, 6.39%, and 86.80%, respectively. Scutch Grass coagulant reduced pH, turbidity, electrical conductivity, and total dissolved solids percentages by 24.80%, 61.24%, 10.73%, and 71.82%, respectively. Table 3 shows these coagulant removal efficiency features. Bitter gourd seed has a considerable impact on total dissolved solids (TDS) clearance when used instead of standard coagulants (alum). It is thought that using low-cost, renewable agricultural or residential waste biomass that requires just a little amount of processing to generate bio-flocculants is a better alternative for this purpose.

Table 3: Removal efficiency of coagulants

Parameter	*Removal efficiency of coagulants*				
	Alum	*Jackfruit peel*	*Banana flower leaf*	*Bitter gourd seed*	*Scutch grass*
pH	35.37%	27.77%,	31.03%,	23.98%,	24.80%,
Turbidity, NTU	83.43%	55.90%,	71.07%,	62.36%,	61.24%,
Electrical conductivity, S/m	4.11%	10.73%	40.64%	6.39%	10.73%
TDS, mg/L	76.81%	80.02 %.	76.81 %.	86.80%	71.82 %

Author Contribution

Venkatesan Govindaraj conceptualised, developed, conducted, analysed, and produced the article. Kalpana Manoharan researched the literature and wrote the article. The final manuscript was reviewed and approved by all writers.

Data Availability

The datasets used and/or analysed during the current investigation are accessible upon reasonable request from the corresponding author.

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