Comparative Analysis of Natural Coagulants, Moringa Oleifera, Urad, Cowpea, and Corn, for Rural Water Treatment

[redacted]

Abstract

Access to potable water is a basic human right and remains a critical challenge, particularly in regions where the river water isn't clean. This study presents a comparative analysis of different seed-based natural coagulants (Moringa Oleifera, Vigna Mungo (Urad), Vigna Unguiculata (Cowpea), and Zea Mays (Corn)) combined with a consistent natural filter for purifying rural tap water. Recent research has highlighted the potential of low-cost, naturally occurring materials as effective solutions for rural water purification. This study addresses the gap in existing literature by testing multiple coagulants under consistent filtration conditions to determine which is the best-performing coagulant.

The results showed that Moringa Oleifera consistently outperformed other coagulants, achieving the greatest reductions in TDS (Total Dissolved Solids), turbidity, and hardness while maintaining pH stability. Cowpea was found to be effective for the reduction in turbidity, and Corn extract showed moderate TDS reduction. Urad exhibited average performance in all tested parameters. All treated samples, except for Corn in the case of turbidity and Cowpea in the case of TDS, met the WHO (World Health Organization) guidelines for safe drinking water.

To test this, a consistent multilayer natural filtration prototype was used, with a single source of rural municipal tap water sample, which was first treated with each of the four coagulants and then passed through the filter. Turbidity, TDS, pH, sulphate, chlorine, chloride, alkalinity, and total hardness were measured for the sampled water, after the coagulation stage and after filtration, to assess the performance of the coagulants.

Keywords: Water Science, Water Resources Management, Rural Water Purification, Natural Coagulants, Multistage Filtration

Introduction

Access to clean drinking water remains a huge challenge, especially in many rural areas where getting an expensive filter isn't feasible. In many regions of India, sewage systems are dysfunctional. According to recent studies, rivers like the Yamuna, which serve as water sources for millions, are severely polluted due to untreated sewage, industrial effluents, and agricultural runoff, resulting in high BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) levels, low dissolved oxygen, and unsafe microbial contamination (Srivastava et al., 2025). Considering the poor quality of sewage treatment and the large population without access to safe water, it becomes crucial to develop a cheap and do-it-yourself (DIY) method for water purification.

Filtration works in two steps: first, particles move towards the filter (transportation), and then they attach to the filter surface (attachment). Particles move through the water using processes like diffusion, interception, or settling, depending on their size (O'Melia & Stumm, 1967). Small particles are best removed by diffusion, while larger particles settle or get caught as they pass through the filter (Yao et al., 1971). These particles need to be treated chemically, using coagulants. This helps them form larger chunks of impurities, called coagulates, which makes them easier to trap in the filter and remove from the water (Ntibrey et al., 2020), as shown in the *Figure 1*.

This is central to understanding how different coagulants like Moringa Oleifera affect the properties of the water after it is filtered. This study compares natural coagulants by first coagulating a consistent sample of raw water taken from a tap in a rural region and then filtering the same water through a consistent multi-stage natural filter.

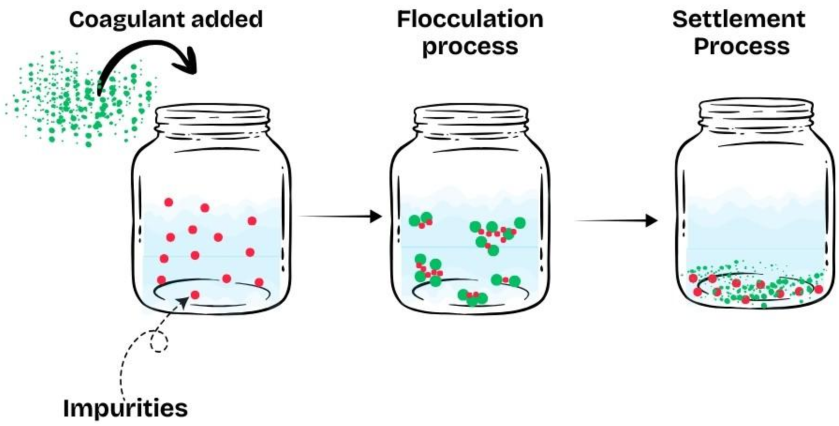

Figure 1

Formation of larger chunks of impurities during coagulation process. Adapted from: Beyene et al (2016).

For improving various quality parameters of water, natural filters and coagulants play an extremely important role. In this study, vital parameters like Total Dissolved Solids (TDS), pH, turbidity, sulphates, chlorine, chloride, alkalinity, and total hardness were tested. These coagulants aggregate suspended impurities in water, which makes it easier to remove them during the filtration process. This is the reason why both Turbidity and TDS are reduced after coagulation, as noted in Sirbadgi et al., 2024, where TDS and Turbidity were both reduced by 69.2% and 92.7% respectively. The process also stabilized pH levels, neutralizing acidic or basic components to bring the water closer to neutral conditions, as demonstrated with Moringa Oleifera seed powder. The process of coagulation reduces the quantum of harmful contaminants like chloride and sulphates, and improves hardness and alkalinity (Nzeyimana & Mary, 2024). The process of filtration followed by coagulation is an effective procedure to make water safer for drinking.

Several studies have explored the development of low-cost filtration systems for rural communities. They often use simple, affordable materials such as sand, activated charcoal, ceramic discs, and rice husk ash (Lakhote et al., 2016; Henry Michael et al., 2013). While most focus on physical or adsorptive filtration, only a smaller set of researchers has incorporated naturally available coagulants to enhance performance. Chauhan et al. (2015) reported the significant coagulation and antimicrobial properties of Moringa Oleifera, Vigna Mungo (Urad), Vigna Unguiculata (Cowpea), and Zea Mays (Corn). It showed up to 92% microbial count reduction. Ntibrey et al. (2020) showed that combining Moringa Oleifera with a filter achieved 98% turbidity removal and 99% elimination of E. coli and coliform bacteria.

Despite these promising results, there remains a lack of comparative studies evaluating different natural coagulants under consistent filtration setups. This study addresses that gap by testing four seed-based coagulants—Moringa Oleifera, Urad, Cowpea, and Corn—under identical experimental conditions, paired with a single multi-stage filter made from natural materials.

The objective of the study is to identify which of the natural coagulants— Moringa Oleifera, Urad, Cowpea or Corn—performs best in improving water quality. The raw water sample was coagulated and filtered. The filtered water was tested for total dissolved solids (TDS), pH, turbidity, sulphate (AE 209), chlorine (AE 246), chloride (AE 213), alkalinity (AE 214), and total hardness (AE 211). These tests were performed on raw water, on water after coagulation, and on final filtered water to determine the effect of each process and assess the effectiveness of each coagulant.

The result from this study exhibited that amongst the four tested coagulants, Moringa Oleifera showed the maximum improvement in all the parameters tested, achieving the highest reductions in TDS, turbidity, and hardness, while maintaining pH. Cowpea also performed strongly in turbidity removal but was less effective in lowering TDS. Corn extract showed moderate TDS reduction but underperformed in turbidity removal, and Urad displayed balanced yet less pronounced improvements across the parameters. All treatments, except for Corn for turbidity, produced water that met WHO guidelines for safe drinking water.

This paper is structured as follows: Section 2 describes the experimental setup, materials, and methodology. Section 3 depicts the results of each coagulant. Section 4 concludes the study and depicts the main findings, limitations of our study, and future research directions.

Methods and Materials

Materials

A consistent, natural, multi-layered DIY filter was used to compare the coagulants. First, the Coagulant pre-treatment was done, followed by a multi-stage natural filter. The materials used were as follows:

Coagulant Pretreatment

Before filtration, raw water was treated with one of the four natural coagulants: Moringa Oleifera, Urad (Vigna Mungo), Cowpea (Vigna Unguiculata), and Corn (Zea Mays) seed extracts. These plant-based substances act as flocculants, helping suspended particles and microorganisms clump together (Madsen et al., 1987). The study evaluates which of these coagulants is the most efficient. The coagulants were chosen as they were easily available, farmed locally, and cost-effective. The seeds were ground using a household mixer grinder to achieve a fine powder, as depicted in the *Figure 2*.

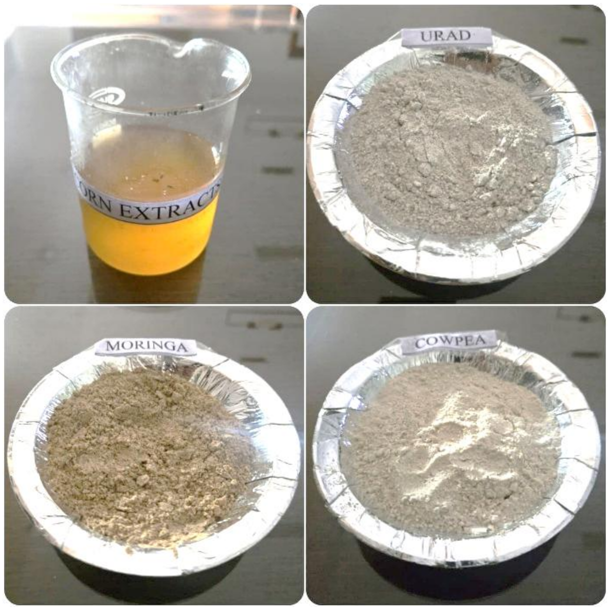

Figure 2

Four coagulants used for the coagulation. Corn Extract, Urad, Moringa Oleifera, and Cowpea.

Filter Structures

After coagulant pretreatment, water passes through the following layers, arranged from top to bottom (as shown in *Fig. 3*):

Cotton Pre-filter. A clean cloth layer was used to trap coarse sediment and large debris before water entered the main system. While not effective for microbial removal on its own, it plays a vital role in reducing turbidity. Cloth filters have been shown to significantly reduce microbial load by capturing carriers of waterborne pathogens and to lower cholera incidence in areas where boiling water is not possible (Colwell et al., 2003).

Sand–Gravel Filter. The mechanical filtration stage includes:

Medium Gravel. Distributes water evenly across the layer.

Fine Sand. Traps dirt and suspended particles.

Coarse Gravel. Supports the filter structure and aids drainage.

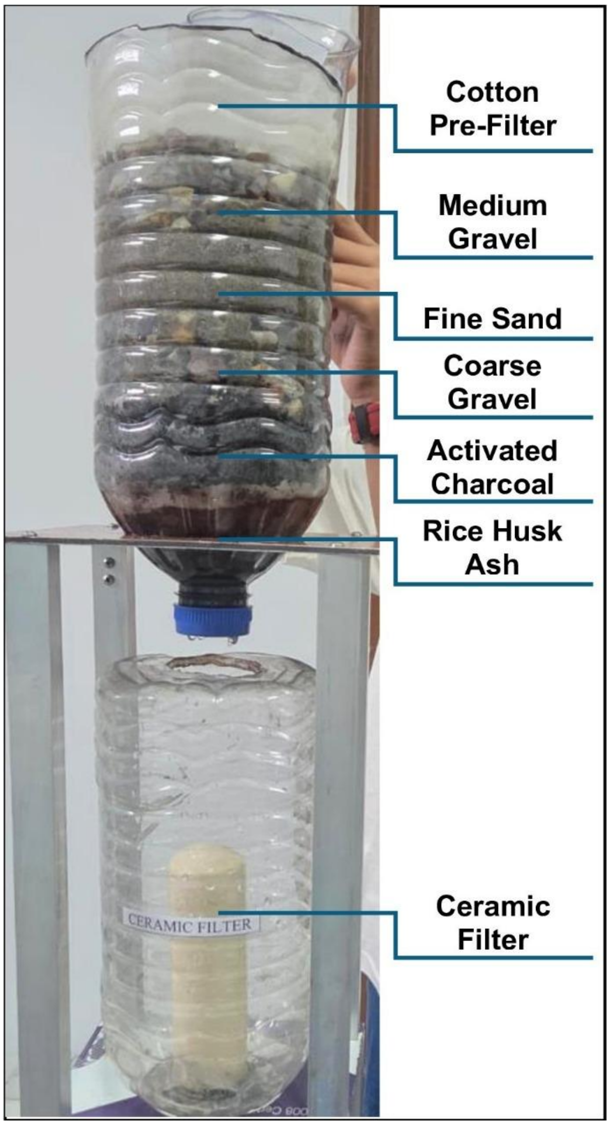

Figure 3

A consistent, natural, multi-layered DIY filter was used to compare the water after coagulation.

This configuration removes most visible impurities and reduces turbidity before water passes into finer filtration layers. Its effectiveness depends on the grain size (Lakhote et al., 2016).

Activated Charcoal Filter. Activated charcoal was included for its ability to trap pollutants and remove odours, colours, and synthetic impurities from water. (Ajaybhaskar Reddy et al., 2023).

Rice Husk Ash Layer. Produced from finely burned and sifted rice husks, this layer is rich in amorphous silica. Modified rice husk ash has been shown to remove up to 98% of arsenic from contaminated water (Javed et al., 2022).

Ceramic Filter Unit. A ceramic filter was used as the final filter media, serving as a fine-pore barrier capable of reducing turbidity and removing 77–96% of E. coli from water (Bulta & Michael, 2019).

Testing Parameters

For raw water, coagulated water, and final filtered water, the following parameters were measured: turbidity, total dissolved solids (TDS), pH, sulphate (AE 209), chlorine (AE 246), chloride (AE 213), alkalinity (AE 214), and total hardness (AE 201 and AE 211).

The equipment used to test various parameters included:

1. pH- Demeteries pH testing kit.
2. TDS- KENT Digital TDS Meter.
3. Chlorine- (AE 246) Aquasol.
4. Turbidity - Demeteries turbidity testing kit.
5. Total Hardness - (AE 211) Aquasol.
6. Sulphates- (AE 209) Aquasol.
7. Alkalinity- (AE 214) Aquasol.
8. Chloride (AE 213) Aquasol.

Methods

Sampling

The water sample was collected from a nearby rural area, sourced from the municipal tap supply. It was selected as it reflects the general water quality available in most rural areas and is considered to have higher contamination levels.

The procedure was as follows:

Coagulation. For each trial, the water sample was placed in a clean container and treated with the powdered form of the assigned coagulant at a concentration of 2g/l. The mixture was stirred continuously for 60 minutes using a homogeniser mixer to ensure an effective coagulation process. It was then left undisturbed for 30 minutes to allow floc (aggregate of impurities) formation and sedimentation. Following the settling period, it was carefully passed through the multi-stage filtration unit.

Filtration. After the coagulation, the clear supernatant was passed through the multistage filtration unit described in the materials section above. The filtration was conducted without any external force and only under gravitational flow; the average processing time for each sample was about 30 minutes. Between trials, the filtration unit was rinsed with distilled water to avoid any cross-contamination.

Testing. The tests for all the parameters were performed on the raw water sample, on the water after coagulation, and on the water after filtration. The filtered raw water without coagulation was also tested. All the tests were repeated three times, and the average figures were recorded. All tests were carried out according to the guidelines provided in the respective testing kits and performed under controlled laboratory conditions.

Results and discussion

pH

The World Health Organization (WHO) recommends that the pH of drinking water should be between 6.5 to 8.0. The values outside this range can cause corrosion, scaling, or unwanted taste (WHO, 2008). The water with pH values below 4 or above 11 causes corrosive injury to the mouth, throat, and digestive tract; it can also be acutely toxic.

The results in this study indicated a pH of 6.4 for tap water, which is just below the acceptable minimum. After filtration without any coagulation process, the pH increased to 7.6, indicating that the multilayer filtration process itself helps neutralize the slight acidity.

A slight increase in pH was also observed in the filtrate of the coagulated water. The following results were observed. These are plotted against the acceptable range in the *Figure 4*

Moringa Oleifera: 7.9

- Urad (Vigna Mungo): 7.9
- Cowpea (Vigna Unguiculata): 7.9
- Corn (Zea Mays): 7.6

These results show that the leguminous seed-based coagulants (Moringa Oleifera, Urad, and Cowpea) mildly increase the pH, due to the presence of basic organic compounds like proteins and alkaloids in the seed extracts. Most importantly, all pH values remained within the WHO guidelines, making the water safe for drinking.

These results are consistent with the findings of Chales et al. (2022), who reported that Moringa Oleifera stabilizes the pH. A review by Alazaiza et al. (2025) also confirms that natural coagulants preserve pH during treatment.

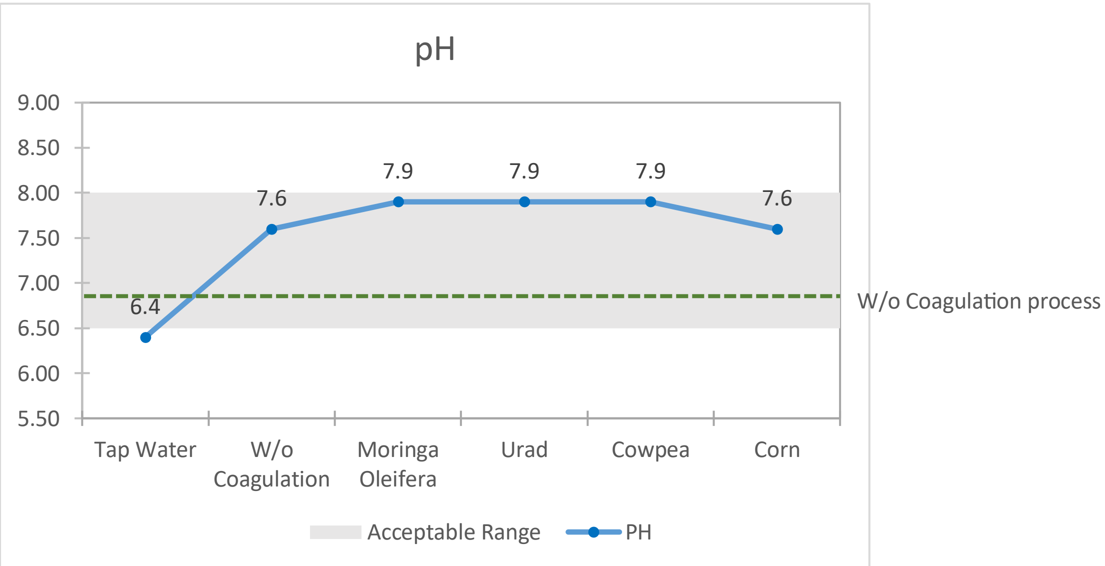

Figure 4

Observed pH, plotted for each of the coagulants after filtration process, the highlighted area shows the acceptable range.

TDS

The WHO guidelines recommend that the TDS be below 300ppm for drinking water (WHO, 2008). Values above this affect taste gravely and thus are not suitable for human consumption. Values above this also signal that the water sample contains salts, minerals, or harmful contaminants like nitrates, arsenic, and lead, which can have adverse health effects. Salinity, which is also signalled by high TDS, can lead to severe diseases like cardiovascular disease, inflammation, and infection.

The water sample collected in the study showed a TDS of 335 before any treatment, which is marginally above the WHO limit. After basic filtration without coagulants, the TDS decreased only slightly to 314 ppm, indicating a limited impact from filtration alone.

The following TDS results were observed in the filtrate of the coagulated water. These are plotted against the acceptable range in the *Figure 5.*

- Moringa Oleifera: 250 ppm.
- Urad (Vigna Mungo): 300 ppm.
- Cowpea (Vigna Unguiculata): 332 ppm.
- Corn extract: 280 ppm.

The biggest improvement was shown by Moringa Oleifera, which reduced the TDS to well below the acceptable threshold. This indicates the usefulness of Moringa Oleifera in reducing TDS. Corn extracts were also extremely useful in lowering TDS. Urad and Cowpea, on the other hand, did not indicate a satisfactory level of TDS.

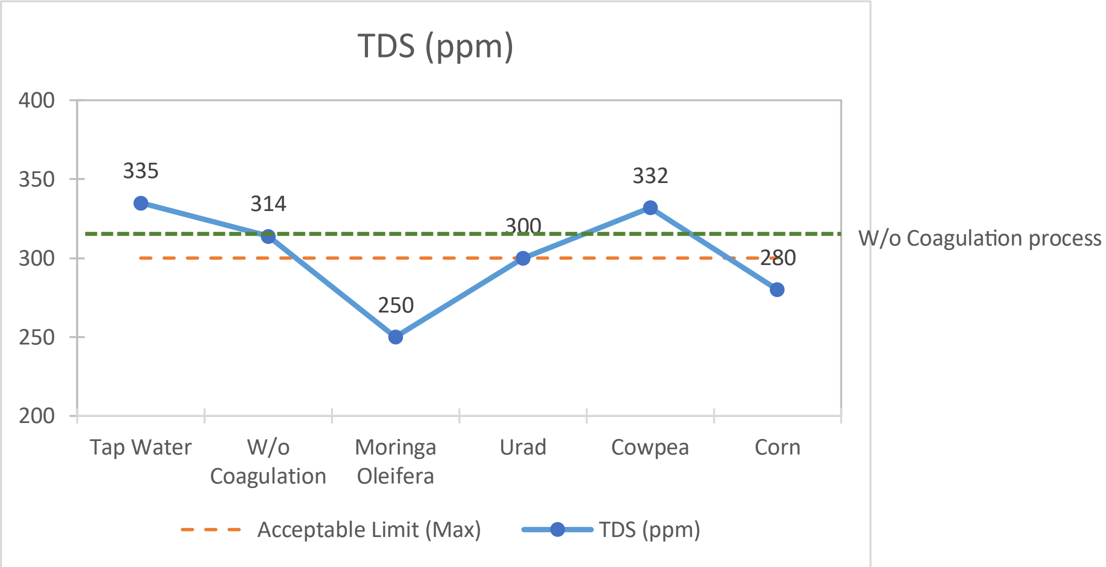

Figure 5

Observed TDS (ppm), plotted for each of the coagulants after filtration process, the dotted line is the maximum acceptable limit.

In this study, the TDS was measured using a conductivity-based meter, which estimates TDS by calculating the electrical conductivity of the water and then multiplying it by a factor of 0.5-0.7. This method doesn't differentiate between truly dissolved ionic solids and weakly charged colloids or organics (it is worth noting that weakly charged colloids or organics can also pose a harm to our health). As such, an EC-based TDS meter may overestimate TDS in the presence of weakly charged colloids or organics, and underestimate it when the water contains many uncharged dissolved solids (Rusydi, 2018). In contrast, the gravimetric method involves evaporating a known volume of water and weighing the dry residue, thus measuring only truly dissolved solids.

While the accuracy limitations of EC-based TDS meters are well recognized in scientific literature, in practice, especially in fieldwork and community-level testing, these devices are widely used because of their speed, portability, low cost, and reliability for relative comparisons (WHO, 2017; Rusydi, 2018). The gravimetric method is extremely tedious and requires days and perfect laboratory conditions to measure it, which was not possible. In the context of our study, this reliance on EC-based TDS measurements represents a limitation, as it may not fully reflect the true changes in dissolved solids following coagulation and filtration. But still, it does indicate the removal of potentially harmful weakly charged colloids or organics, indicating the usefulness of coagulants like Moringa Oleifera.

The TDS reduction observed in our study is attributed to the coagulants' ability to neutralize and bind charged colloidal or weakly dissolved organic matter, forming flocs which are then removed by sedimentation and filtration. These flocs no longer contribute to conductivity, leading to lower EC and thus lower TDS readings on the meter. This is supported by Sirbadgi et al. (2024), who observed up to 69.2% TDS reduction using plant-based coagulant.

Thus, while true ionic TDS (gravimetric) may remain partially unaffected, the reduction seen on a TDS meter (EC-based) is real and relevant, especially when considering the perceived quality and operational safety of drinking water. A significant reduction of TDS was seen after the filtration process, as it was reduced from 335ppm to 250ppm using Moringa Oleifera as a coagulant, which is also consistent with the reduction seen in literature. In sum, natural coagulants, especially Moringa Oleifera and Corn extract, display a vast reduction in TDS because of their ability to flocculate (cause fine suspended particles to clump together into aggregates or flocs, thus making them easier to remove) semi-dissolved and colloidal impurities. While they may not be considered truly dissolved, salts can be detected by gravimetric analysis; their effect on the water quality remains significant. The distinction between EC-based and gravimetric TDS should be recognized in both research and practical applications.

Chlorine

The WHO guidelines recommend that the Chlorines in potable water should be between 0.2-5.0 ppm. Chlorine was not detected in the original water sample, indicating that it is not present in the municipal tap water (in the area where the study was conducted). It was also not found in the water samples tested after coagulation and after filtration, signifying that coagulation doesn't lead to the addition of chlorine to the water.

Turbidity

The WHO recommends that the turbidity of potable water be below 5 NTU (Nephelometric Turbidity Unit). Anything above this value promotes the growth of microorganisms, which could be dangerous to health. Turbidity above 5 NTU also indicates that the water sample contains the presence of suspended solids and harmful pathogens that can be agents for diseases. (WHO, 2017).

In this study, the turbidity of the original tap water sample was observed at 14 NTU, which exceeds the WHO guideline and indicates a high level of harmful particulate matter. Filtration without coagulation reduced turbidity to 1 NTU, which showed the effectiveness of the multilayer filtration media in removing suspended solids.

The following turbidity results were observed in the filtrate of the coagulated water. These are plotted against the acceptable range in the *Figure 6.*

- Moringa Oleifera: 1 NTU
- Urad (Vigna Mungo): 3 NTU
- Cowpea (Vigna Unguiculata): 1 NTU
- Corn (Zea Mays): 7 NTU

These results indicate that amongst all four coagulants used for filtration, Moringa Oleifera, and Cowpea were the most effective, as both displayed a turbidity of 1 NTU. The other two coagulants, Urad and Corn, displayed the turbidity values of 3 and 7 NTU, respectively. Urad was within the WHO guidelines, but the turbidity of Corn exceeds the WHO limit and therefore indicates incomplete removal of suspended matter.

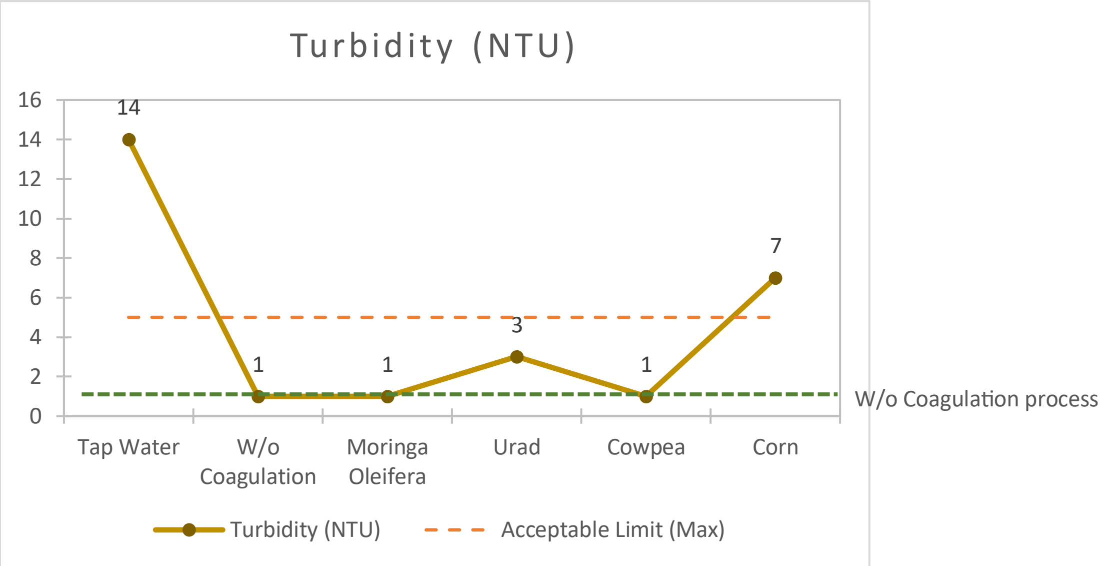

Figure 6

Observed Turbidity (NTU), plotted for each of the coagulants after filtration process, the dotted line is the maximum acceptable limit.

These findings are consistent with the results of Mangale et al. (2012), who reported that Moringa Oleifera seed extract reduced turbidity by over 90% in surface water samples, outperforming several other plant-based coagulants tested under similar conditions.

Total hardness

The World Health Organization (WHO) recommends that the total hardness of drinking water should be below 500 ppm as calcium carbonate, as higher levels can cause scaling in pipes, affect soap lathering, and contribute to taste changes (WHO, 2017). While hardness is not considered a direct health hazard, very high levels have been associated with, in extreme cases, kidney stone formation. (WHO, 2017)

In this study, the hardness of the tap water sample was found to be 250 ppm, which is below the acceptable limit. Filtration without coagulation, the hardness increased to 375 ppm, which is likely because of the leaching of minerals such as calcium and magnesium from the filtration media. This increase is also not concerning since it is very well below the WHO guidelines.

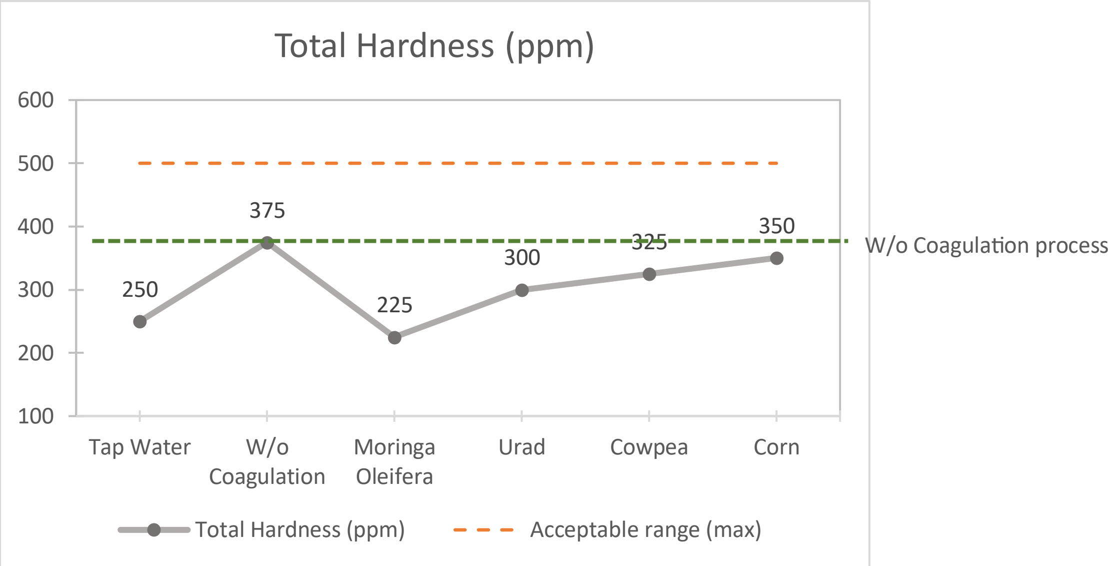

Figure 7

Observed Total Hardness (ppm), plotted for each of the coagulates after filtration process, the dotted line is the max acceptable limit.

The following Total Hardness results were observed in the filtrate of the coagulated water. These are plotted against the acceptable range in the *Figure 7.*

- Moringa Oleifera: 225 ppm
- Urad (Vigna Mungo): 300 ppm
- Cowpea (Vigna Unguiculata): 325 ppm
- Corn (Zea Mays): 350 ppm

The results of this study show that Moringa Oleifera was the best in reducing the total hardness of water. Urad and Cowpea were also effective for this purpose. Corn was the least effective for this purpose. It is important to note that all values remained below the WHO limit and thus are safe for human consumption in the total hardness parameter.

Sulphate, Alkalinity, and Chloride

Sulphate ion concentration in drinking water is recommended to be less than 500 ppm, as anything beyond that can cause a bitter taste and gastrointestinal discomfort (WHO, 2017). The tap water contained 120 ppm, which increased to 160 ppm after filtration without coagulation, likely due to mineral leaching from the filter media. After coagulation, Moringa Oleifera and Cowpea showed higher sulphate levels at 180 ppm, whereas Urad and Corn maintained the original concentration at 120 ppm. All recorded sulphate levels were well below the WHO guideline value.

The recommended alkalinity range for potable water by the WHO is 20–200 ppm as $CaCO_3$, as it helps buffer pH and prevents rapid changes in acidity and alkalinity (WHO, 2017). The tap water sample measured well within this range at 75 ppm, remaining the same without coagulation after filtration. Moringa Oleifera and Urad both reduced it to 25ppm, and Cowpea increased it to 100 ppm, and Corn reduced it to 50 ppm. All the results observed were in the acceptable range.

The WHO recommends that the chloride in water should be less than 250 ppm, as it can cause issues with taste (WHO, 2017). In this study, the original tap water had a chloride level of 8ppm, which is well below the acceptable limit. Filtration with coagulants didn't change this much. Among the coagulants, Moringa Oleifera showed an increase to 20 ppm, while Urad reduced it to 6 ppm. In comparison, Cowpea and Corn both resulted in 8 ppm, showing minimal changes in chloride content across most treatments, and showing that neither tap water nor water after coagulation contains any concerning amounts of chloride.

Overall, the samples before and after the filtration of water were safe for human consumption on the parameters of chloride, alkalinity, and sulphate. Observed chlorides, alkalinity, and sulphates are plotted in the *Figure 8.*

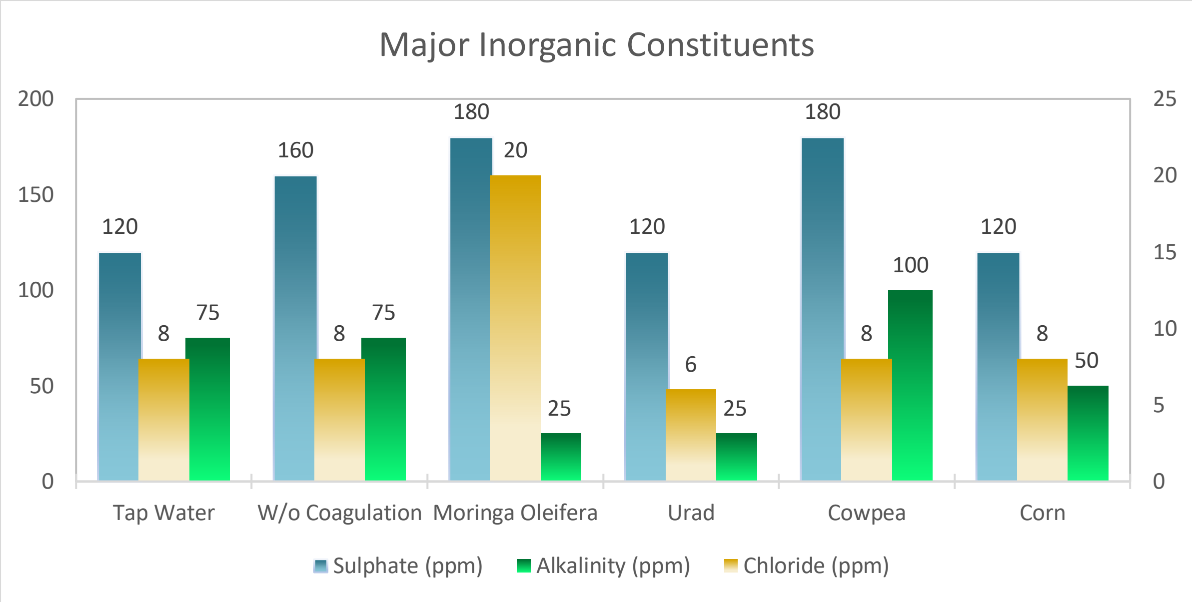

Figure 8

Observed Sulphates (ppm) and Alkalinity (ppm), plotted on left Y axis, and Chlorides (ppm), plotted on right Y Axis, for each of the coagulants after filtration process.

Conclusion

This study evaluated the performance of four seed-based coagulants (Moringa Oleifera, Vigna Mungo (Urad), Vigna unguiculata (Cowpea), and Zea Mays (Corn)) when paired with a consistent DIY natural filtration system in improving the quality of rural tap water. It was tested across parameters, which included pH, TDS, turbidity, total hardness, chloride, alkalinity, and sulphate (summarized in *Table 1, Appendix 1*). All the tested samples after filtration and coagulation were within the guidelines recommended by WHO, apart from Cowpea for TDS and Corn for Turbidity, which both exceeded the limits.

Moringa Oleifera was shown to be the best across all parameters, as it consistently outperformed the other coagulants tested. It achieved the highest reduction in TDS, turbidity, and hardness, while maintaining pH stability. Cowpea also achieved strong turbidity removal but showed less improvement in TDS. Corn extract was moderately effective for TDS but underperformed in turbidity reduction. Urad provided balanced but less pronounced improvements across all the parameters.

The study shows that combining natural coagulants and a multi-layered natural filter can significantly improve water quality, offering a solution to the communities that lack centralized treatment infrastructure.

Future research

While the results of this paper are promising, several aspects need to be explored further to improve the practicality and scalability of this approach.

- Scalability of the System- future work needs to focus on making this design into a household modular design that can be capable of treating single household requirement of water per day.
- Fast and less tedious coagulation- the current method requires stirring for more than 60 minutes, which is impractical for large-scale or household use. Future research should aim to develop faster and more practical coagulation methods suitable for large-scale or household applications.
- Testing Across Diverse Water Sources- This study sampled water from a rural North Indian municipal tap supply. Additional trials should be conducted on various other types of water, like water near the sea, which would have more chloride content, water from downstream areas, or a highly turbid pond, and test which coagulants perform best in those waters.
- Pathogen removal assessment – The source of the water used in this study is municipal tap water, which comes from the river Ganga. Ganga water contains Bacteriophage, which removes bacteria and pathogens (Bahera et al., 2022). Further studies should test water sources with pathogens to evaluate the antimicrobial effectiveness of these coagulants.

Future research on these areas could help transition this approach from theory to practical, low-cost solutions. This could lead to a solution to the problem of unsafe water and lead to a world where all people realize their right to clean and potable water.

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Appendix 1

Table 1 summarizes the results observed for the tested parameters of raw water and the filtrates after the coagulation process. The corresponding WHO guidelines are also provided for the better understanding of the improvements in the water quality achieved.

Table 1

Results of Water Quality Parameters Before and After Coagulation Treatment

	WHO Guidelines	Tap Water	W/o Coagulation	Moringa Oleifera	Urad	Cowpea	Corn
pH	6.5-8.0	6.4	7.6	7.9	7.9	7.9	7.6
TDS (ppm)	<300	335	314	250	300	332	280
Chlorine (ppm)	0.2-5.0	ND	ND	ND	ND	ND	ND
Turbidity (NTU)	<5	14	1	1	3	1	7
Total Hardness (ppm)	<500	250	375	225	300	325	350
Sulphate (ppm)	<500	120	160	180	120	180	120
Alkalinity (ppm)	20-200	75	75	25	25	100	50
Chloride (ppm)	<250	8	8	20	6	8	8

ND: Not detected

Reviewer Recommendation
Accept with minor revisions

Overall Impression
This is an impressive and well-executed study by an early-career researcher. The manuscript addresses a highly relevant and practical issue—access to clean water in rural communities—through a clear, methodical investigation of low-cost, natural water treatment solutions. The research is motivated by a clear gap in the literature, and the experimental design is robust and appropriately described. The writing is generally clear, and the results are presented logically, with supporting figures and a helpful summary table. The work demonstrates strong engagement with existing research and applies sound scientific methodology. With some minor revisions to strengthen the clarity, context, and discussion, this paper will be a valuable contribution to the field.

Strengths
- Originality & Significance: The comparative approach under consistent filtration conditions is a meaningful contribution. While individual coagulants like Moringa have been studied, direct comparisons like this are less common and highly useful for practical application.
- Clarity & Structure: The paper is well-organized, following a standard scientific format. The objectives are clear, and the flow of information is logical.
- Methodology: The experimental design is sound. Using a consistent water source and filter prototype for all coagulants allows for a fair comparison. Repeating tests three times is good practice. The parameters tested are relevant to water safety.
- Engagement with Literature: The author successfully situates their work within existing research, citing appropriate studies to justify their methods and support their findings.

Areas for Improvement and Suggestions for Minor Revisions:

1. Introduction Context:
   - The introduction effectively sets the stage but could be slightly more focused. Consider tightening the connection between the pollution problem (e.g., Yamuna River) and the specific water quality parameters tested (TDS, turbidity, etc.) earlier on. Briefly state what these parameters indicate about water safety to immediately orient the reader who may be less familiar with water science.

2. Methodological Detail:
   - The concentration of coagulant used (2g/l) is stated, but a brief justification for choosing this specific dosage would strengthen the methods section. Was this based on prior literature? A quick sentence would suffice.
   - Clarify the phrase "homogeniser mixer" – was this a standard magnetic stirrer, a jar test apparatus, or something else? Using more standard terminology improves reproducibility.

3. Discussion of Results:

- The discussion of TDS is excellent and very thoughtful, correctly identifying the limitation of the conductivity-based method and its implications. This shows deep understanding.
- For other parameters, the discussion could be slightly deepened. For instance, why might the hardness have “increased” after filtration without coagulation? The hypothesis about mineral leaching is good; stating it more explicitly would be beneficial. Similarly, speculating briefly on “why” Moringa outperformed the others (e.g., unique properties of its cationic proteins) would elevate the discussion.
- The conclusion states Cowpea for TDS and Corn for turbidity exceeded WHO limits, but the results in Fig 5 and the table show Cowpea TDS at 332 ppm (>300 ppm limit) and Corn turbidity at 7 NTU (>5 NTU limit). This is correct, but ensure this discrepancy between the text and the visual/data is consistently clear.

4. Grammar and Language:
- The language is very good for a high school scholar. There are minor grammatical errors and slightly awkward phrasings throughout (e.g., "The biggest improvement was shown by...", "Urad displayed balanced yet less pronounced improvements..."). A careful proofread is recommended. For example:
    - "This study presents a comparative analysis of different seed-based natural coagulants..." -> "This study presents a comparative analysis of four seed-based natural coagulants..."
    - "The process of filtration followed by coagulation is..." -> "The process of coagulation followed by filtration is..." (based on the described order of operations).
- These are minor and easily correctable.

5. Formatting:
- Check the consistency of species names. They should be in italics (e.g., Vigna mungo, Zea mays) upon first use, and thereafter can be referred to by common name.
- Ensure all figures are clearly labeled and referenced in the text.

Review Report

Paper title- Comparative Analysis of Natural Coagulants, Moringa Oleifera, Urad, Cowpea, and Corn for Rural Water Treatment

Final recommendation- Minor revisions

Note:

- Author's original lines are highlighted in **red.**
- Reviewer comments are provided in **black**.

This baseline study offers practical insights into addressing basic needs, particularly access to clean drinking water. By demonstrating a simple filtration method using locally available materials and seed based coagulants, the study presents a viable solution for household-level water treatment. The inclusion of the study area adds further relevance, showing where such approaches can be realistically implemented and scaled to benefit rural communities.

Title:

The current title may be too specific in mentioning the plant species used. It is recommended to generalize the title to better reflect the broader relevance of the study. Below are suggested alternatives:

1. Harnessing Indigenous Crops for Sustainable Water Treatment in Rural Communities
2. Natural Coagulants for Rural Water Security: Implications for Climate-Resilient and Low-Cost Treatment Solutions
3. Optimising Rural Water Quality Using Indigenous Plant-Based Coagulants: A Comparative Analysis

Abstract

- **Line 4: Please write *"Moringa"* which is common name of "moringa olefiera" to maintain consistency with the naming style used for other plants in the line.**
- **Line 6: The word *"solutions"* should be corrected to "solution" for grammatical accuracy.**
- **Paragraph Placement: The final paragraph currently placed at the end of the introduction—*"To test this, a consistent multilayer natural filtration prototype was used,…"*—should be moved ahead of results paragraph. It describes the experimental setup and is better suited to precede the results.**

Introduction

- In this study, vital parameters like Total Dissolved Solids (TDS), pH, turbidity, sulphates, chlorine, chloride, alkalinity, and total hardness were tested.

- **You should explain first how these parameters are linked with good quality water and then explain the changes in parameters and degrading quality.**

This is the reason why both Turbidity and TDS are reduced after coagulation, as noted in Sirbadgi et al., 2024, where TDS and Turbidity were both reduced by 69.2% and 92.7% respectively.

- **Remove direct result statements: Avoid including specific findings such as *"99% elimination of E. coli and coliform bacteria"* in the introduction. These are results and should be discussed in the Results or Discussion sections. Instead, you can refer more generally to the types of contaminants being addressed.**

99% elimination of E. coli and coliform bacteria

- **Since *E. coli* is a subset of coliform bacteria, it is sufficient to refer to *coliform bacteria* alone unless there is a specific reason to distinguish between them in your analysis.**

The raw water sample was coagulated and filtered. The filtered water was tested for total dissolved solids (TDS), pH, turbidity, sulphate (AE 209), chlorine (AE 246), chloride (AE 213), alkalinity (AE

214), and total hardness (AE 211). These tests were performed on raw water, on water after coagulation, and on final filtered water to determine the effect of each process and assess the effectiveness of each coagulant.

The result from this study exhibited that amongst the four tested coagulants, Moringa

Oleifera showed the maximum improvement in all the parameters tested, achieving the highest reductions in TDS, turbidity, and hardness, while maintaining pH. Cowpea also performed strongly in turbidity removal but was less effective in lowering TDS. Corn extract showed moderate TDS reduction but underperformed in turbidity removal, and Urad displayed balanced yet less pronounced improvements across the parameters. All treatments, except for Corn for turbidity, produced water that met WHO guidelines for safe drinking water.

The last two paragraphs of the introduction currently provide a summary of the paper's findings and whole manuscript. It is strongly recommended to remove these, as the introduction should focus on background, rationale, and objectives—not previewing results or conclusions.

Study Area

Instead of using a general phrase like *"nearby rural area"*, it is important to clearly state the name of the study area from which water samples were collected. This provides geographical context and strengthens the credibility of the research by allowing readers to understand the environmental and regulatory setting of the study.

Use of WHO Standards
Since the results section will refer to WHO permissible limits, it is advisable to briefly explain WHO drinking water quality standards in the Introduction. This will help readers understand why WHO guidelines are used as the primary benchmark—especially if the study area falls outside the jurisdiction of national or regional standards such as the EU Drinking Water Directive or the UK Water Supply (Water Quality) Regulations 2016.

In the methodology section, it is recommended to number the headings for clarity and structure.

Materials

1. **Coagulant Pretreatment**
2. **Filter Structures**
3. ***(Add any additional materials here)***

Methods

1. **Sampling**
2. **Coagulation**
3. **Filtration**
4. **Water Quality Testing** ***(use this term instead of just "testing" for precision)***

Results and discussion

It is important to specify the study area when discussing drinking water standards, as parametric values vary across countries and regions. Identifying the location of the study helps justify the choice of reference standards. For instance, while there are EU limits and national regulations such as the UK Water Supply (Water Quality) Regulations 2016, comparisons in this study are made solely against WHO permissible limits.

This is because the study area falls outside the jurisdiction of EU or UK regulations, making WHO guidelines the most appropriate benchmark for international comparison. Therefore, study area is needed to be mentioned in the manuscript.

On page 15- remove these numbers below; as your figure-7 is already indicating these.

• Moringa Oleifera: 225 ppm

• Urad (Vigna Mungo): 300 ppm

• Cowpea (Vigna Unguiculata): 325 ppm

• Corn (Zea Mays): 350 ppm

Please do similar action for below on page-13 as mentioned in figure 6; also page 9 &10 for pH and TDS

Moringa Oleifera: 1 NTU

• Urad (Vigna Mungo): 3 NTU

• Cowpea (Vigna Unguiculata): 1 NTU

• Corn (Zea Mays): 7 NTU

Once your have plotted the data in figure you don't need to replicate these separately.

Throughout the manuscript, please ensure that figure titles are placed on the same line as the figure number, rather than on the following line. This improves readability and consistency.

For example, instead of:

Figure 1
Map showing the study area

It should be formatted as:

Figure 1: Map showing the study area

This formatting should be applied consistently to all figures in the manuscript.

Conclusion

(summarized in Table 1, Appendix 1). Please remove this from conclusion.

Optimising Rural Water Quality Using Indigenous Plant-Based Coagulants: A Comparative Analysis

[redacted]

Abstract

Access to potable water is a basic human right and remains a critical challenge, particularly in regions where the river water isn't clean This study presents a comparative analysis of four seed-based natural coagulants (*Moringa*, *Vigna Mungo* (Urad), *Vigna Unguiculata* (Cowpea), and *Zea Mays* (Corn)) combined with a consistent natural filter for purifying rural tap water. Recent research has highlighted the potential of low-cost, naturally occurring materials as effective solution for rural water purification. This study addresses the gap in existing literature by testing multiple coagulants under consistent filtration conditions to determine which is the best-performing coagulant.

To test this, a consistent multilayer natural filtration prototype was used, with a single source of rural municipal tap water sample, which was first treated with each of the four coagulants and then passed through the filter. Turbidity, TDS, pH, sulphate, chlorine, chloride, alkalinity, and total hardness were measured for the sampled water, after the coagulation stage and after filtration, to assess the performance of the coagulants. The results showed that Moringa Oleifera consistently outperformed other coagulants, achieving the greatest reductions in TDS (Total Dissolved Solids), turbidity, and hardness while maintaining pH stability. Cowpea was found to be effective for the reduction in turbidity, and Corn extract showed moderate TDS reduction. Urad exhibited average performance in all tested parameters. All treated samples, except for Corn in the case of turbidity and Cowpea in the case of TDS, met the WHO (World Health Organization) guidelines for safe drinking water.

Keywords: Water Science, Water Resources Management, Rural Water Purification, Natural Coagulants, Multistage Filtration

Introduction

Access to clean drinking water remains a huge challenge, especially in many rural areas where getting an expensive filter isn't feasible. In many regions of India, sewage systems are dysfunctional. According to recent studies, rivers like the Yamuna, which serve as water sources for millions, are severely polluted due to untreated sewage, industrial effluents, and agricultural runoff, resulting in high BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) levels, low dissolved oxygen, and unsafe microbial contamination (Srivastava et al., 2025). Considering the poor quality of sewage treatment and the large population without access to safe water, it becomes crucial to develop a cheap and do-it-yourself (DIY) method for water purification.

Filtration works in two steps: first, particles move towards the filter (transportation), and then they attach to the filter surface (attachment). Particles move through the water using processes like diffusion, interception, or settling, depending on their size (O'Melia & Stumm, 1967). Small particles are best removed by diffusion, while larger particles settle or get caught as they pass through the filter (Yao et al., 1971). These particles need to be treated chemically, using coagulants. This helps them form larger chunks of impurities, called coagulates, which makes them easier to trap in the filter and remove from the water (Ntibrey et al., 2020), as shown in the *Figure 1*.

This is central to understanding how different coagulants like Moringa Oleifera affect the properties of the water after it is filtered. This study compares natural coagulants by first coagulating a consistent sample of raw water taken from a tap in a rural region and then filtering the same water through a consistent multi-stage natural filter.

Water quality is defined by a range of physio-chemical parameters that determine its suitability for human consumption and ecological balance. In this study, vital parameters like

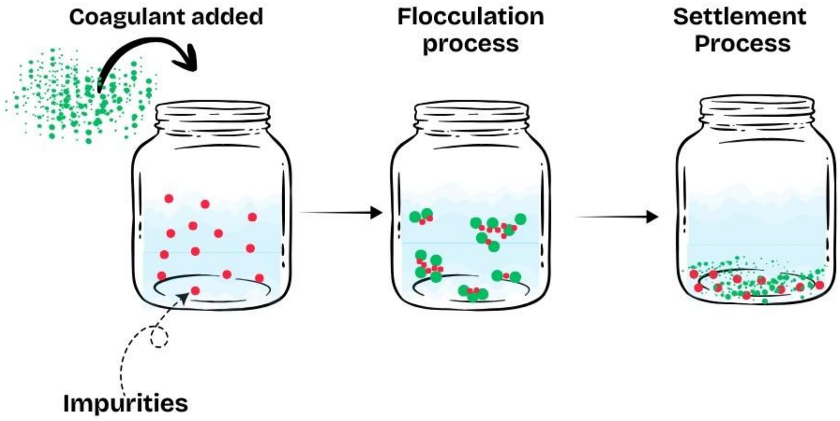

Figure 1: *Formation of larger chunks of impurities during coagulation process. Adapted from: Beyene et al (2016).*

Total Dissolved Solids (TDS), pH, turbidity, sulphates, chlorine, chloride, alkalinity, and total hardness were tested. Total Dissolved Solids (TDS) indicate the concentration of inorganic salts and directly affect taste and potability. pH reflects the acidity or alkalinity of water, with extreme deviations harming health. Turbidity measures suspended particles, which can shield microorganisms from disinfection and signal pollution. Sulphates, chlorine, and chloride, while permissible in small amounts, may cause gastrointestinal discomfort, corrosivity, or unpleasant taste when elevated Alkalinity governs the buffering capacity of water against pH fluctuations, and total hardness, driven by calcium and magnesium levels, influences scaling, taste, and potential health effects. In this study, changes in these parameters were systematically examined.

These coagulants aggregate suspended impurities in water, which makes it easier to remove them during the filtration process. This is the reason why both Turbidity and TDS are reduced after coagulation, as noted in Sirbadgi et al., 2024, where TDS and Turbidity were both reduced. The process also stabilized pH levels, neutralizing acidic or basic components to bring the water closer to neutral conditions, as demonstrated with Moringa Oleifera seed powder. The process of coagulation reduces the quantum of harmful contaminants like chloride and sulphates, and improves hardness and alkalinity (Nzeyimana & Mary, 2024).

The process of coagulation followed by filtration is an effective procedure to make water safer for drinking.

Several studies have explored the development of low-cost filtration systems for rural communities. They often use simple, affordable materials such as sand, activated charcoal, ceramic discs, and rice husk ash (Lakhote et al., 2016; Henry Michael et al., 2013). While most focus on physical or adsorptive filtration, only a smaller set of researchers has incorporated naturally available coagulants to enhance performance. Chauhan et al. (2015) reported the significant coagulation and antimicrobial properties of Moringa Oleifera, Vigna Mungo (Urad), Vigna Unguiculata (Cowpea), and Zea Mays (Corn). It showed up to 92% microbial count reduction.

Despite these promising results, there remains a lack of comparative studies evaluating different natural coagulants under consistent filtration setups. This study addresses that gap by testing four seed-based coagulants—Moringa Oleifera, Urad, Cowpea, and Corn—under identical experimental conditions, paired with a single multi-stage filter made from natural materials.

The objective of the study is to identify which of the natural coagulants— Moringa Oleifera, Urad, Cowpea or Corn—performs best in improving water quality. The raw water sample was coagulated and filtered. The filtered water was tested for total dissolved solids (TDS), pH, turbidity, sulphate (AE 209), chlorine (AE 246), chloride (AE 213), alkalinity (AE 214), and total hardness (AE 211). These tests were performed on raw water, on water after coagulation, and on final filtered water to determine the effect of each process and assess the effectiveness of each coagulant.

This paper is structured as follows: Section 2 describes the experimental setup, materials, and methodology. Section 3 depicts the results of each coagulant. Section 4 concludes the study and depicts the main findings, limitations of our study, and future research directions.

Methods and Materials

Materials

A consistent, natural, multi-layered DIY filter was used to compare the coagulants. First, the Coagulant pre-treatment was done, followed by a multi-stage natural filter. The materials used were as follows:

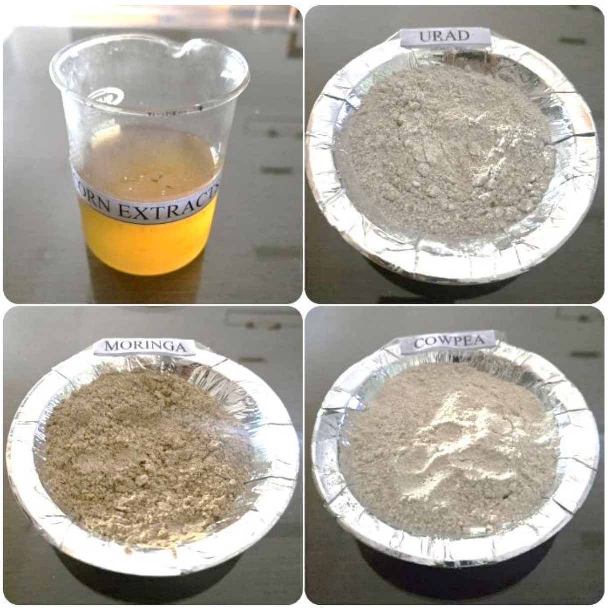

Figure 2: Four coagulants used for the coagulation. Corn Extract, Urad, Moringa Oleifera, and Cowpea.

1. Coagulant Pretreatment

Before filtration, raw water was treated with one of the four natural coagulants: Moringa Oleifera, Urad (Vigna Mungo), Cowpea (Vigna Unguiculata), and Corn (Zea Mays) seed extracts. These plant-based substances act as flocculants, helping suspended particles and microorganisms clump together (Madsen et al., 1987). The study evaluates which of these coagulants is the most efficient. The coagulants were chosen as they were easily available, farmed locally, and cost-effective. The seeds were ground using a household mixer grinder to achieve a fine powder, as depicted in the *Figure 2*.

2. Filter Structures

After coagulant pretreatment, water passes through the following layers, arranged from top to bottom (as shown in *Fig. 3*):

Cotton Pre-filter. A clean cloth layer was used to trap coarse sediment and large debris before water entered the main system. While not effective for microbial removal on its own, it plays a vital role in reducing turbidity. Cloth filters have been shown to significantly reduce microbial load by capturing carriers of waterborne pathogens and to lower cholera incidence in areas where boiling water is not possible (Colwell et al., 2003).

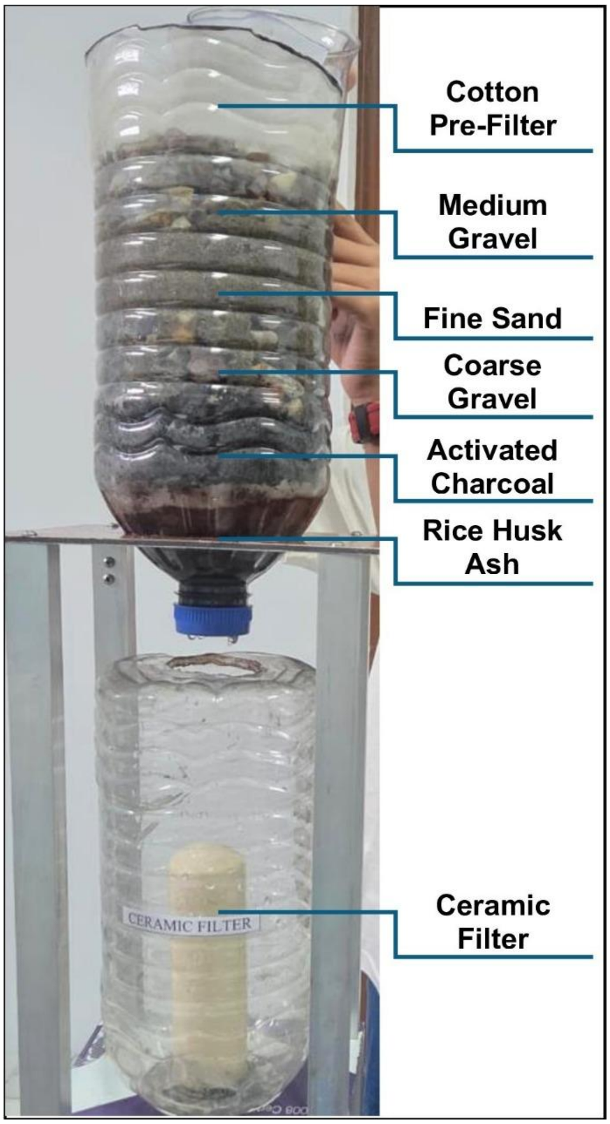

Figure 3: A consistent, natural, multi-layered DIY filter was used to compare the water after coagulation.

Sand–Gravel Filter. The mechanical filtration stage includes:

Medium Gravel. Distributes water evenly across the layer.

Fine Sand. Traps dirt and suspended particles.

Coarse Gravel. Supports the filter structure and aids drainage.

This configuration removes most visible impurities and reduces turbidity before water passes into finer filtration layers. Its effectiveness depends on the grain size (Lakhote et al., 2016).

Activated Charcoal Filter. Activated charcoal was included for its ability to trap pollutants and remove odours, colours, and synthetic impurities from water. (Ajaybhaskar Reddy et al., 2023).

Rice Husk Ash Layer. Produced from finely burned and sifted rice husks, this layer is rich in amorphous silica. Modified rice husk ash has been shown to remove up to 98% of arsenic from contaminated water (Javed et al., 2022).

Ceramic Filter Unit. A ceramic filter was used as the final filter media, serving as a fine-pore barrier capable of reducing turbidity and removing 77–96% of E. coli from water (Bulta & Michael, 2019).

3. Testing Parameters

For raw water, coagulated water, and final filtered water, the following parameters were measured: turbidity, total dissolved solids (TDS), pH, sulphate (AE 209), chlorine (AE 246), chloride (AE 213), alkalinity (AE 214), and total hardness (AE 201 and AE 211).

The equipment used to test various parameters included:

1. pH- Demeteries pH testing kit.
2. TDS- KENT Digital TDS Meter.
3. Chlorine- (AE 246) Aquasol.
4. Turbidity - Demeteries turbidity testing kit.
5. Total Hardness - (AE 211) Aquasol.
6. Sulphates- (AE 209) Aquasol.
7. Alkalinity- (AE 214) Aquasol.

Chloride (AE 213) Aquasol.The apparatus used for coagulation and mixing was a Remi RQ-140/DE Homogeniser

Methods

1. Sampling

The water sample was collected from a small village named Dadupur in Haridwar district in India, sourced from the municipal tap supply. It was selected as it reflects the general water quality available in most rural areas and is considered to have higher contamination levels.

The procedure was as follows:

2. *Coagulation*.

For each trial, the water sample was placed in a clean container and treated with the powdered form of the assigned coagulant at a concentration of 2g/l. The dosage of 2 g/L was selected based on prior studies where similar natural coagulant concentrations demonstrated effective turbidity and contaminant reduction while maintaining water safety (Ntibrey et al., 2020). The mixture was stirred continuously for 60 minutes using a homogeniser mixer to ensure an effective coagulation process. It was then left undisturbed for 30 minutes to allow floc (aggregate of impurities) formation and sedimentation. Following the settling period, it was carefully passed through the multi-stage filtration unit.

3. *Filtration*.

After the coagulation, the clear supernatant was passed through the multistage filtration unit described in the materials section above. The filtration was conducted without any external force and only under gravitational flow; the average processing time for each sample was about 30 minutes. Between trials, the filtration unit was rinsed with distilled water to avoid any cross-contamination.

4. *Testing*.

The tests for all the parameters were performed on the raw water sample, on the water after coagulation, and on the water after filtration. The filtered raw water without coagulation was also tested. All the tests were repeated three times, and the average figures were recorded. All tests were carried out according to the guidelines provided in the respective testing kits and performed under controlled laboratory conditions.

For this study WHO benchmarks for all parameters were used to determine the suitability of the water quality as The World Health Organization (WHO) drinking water quality standards provide globally recognized limits for safe and acceptable water, covering key parameters such as TDS, pH, turbidity, sulphates, chloride, and hardness. Since these guidelines are widely applicable across regions where national or regional standards may not directly apply, they serve as the primary reference point in this study for assessing the suitability of water for human consumption.

Results and discussion

pH

The World Health Organization (WHO) recommends that the pH of drinking water should be between 6.5 to 8.0. The values outside this range can cause corrosion, scaling, or unwanted taste (WHO, 2008). The water with pH values below 4 or above 11 causes corrosive injury to the mouth, throat, and digestive tract; it can also be acutely toxic.

The results in this study indicated a pH of 6.4 for tap water, which is just below the acceptable minimum. After filtration without any coagulation process, the pH increased to 7.6, indicating that the multilayer filtration process itself helps neutralize the slight acidity.

A slight increase in pH was also observed in the filtrate of the coagulated water. These are plotted against the acceptable range in the *Figure 4.*

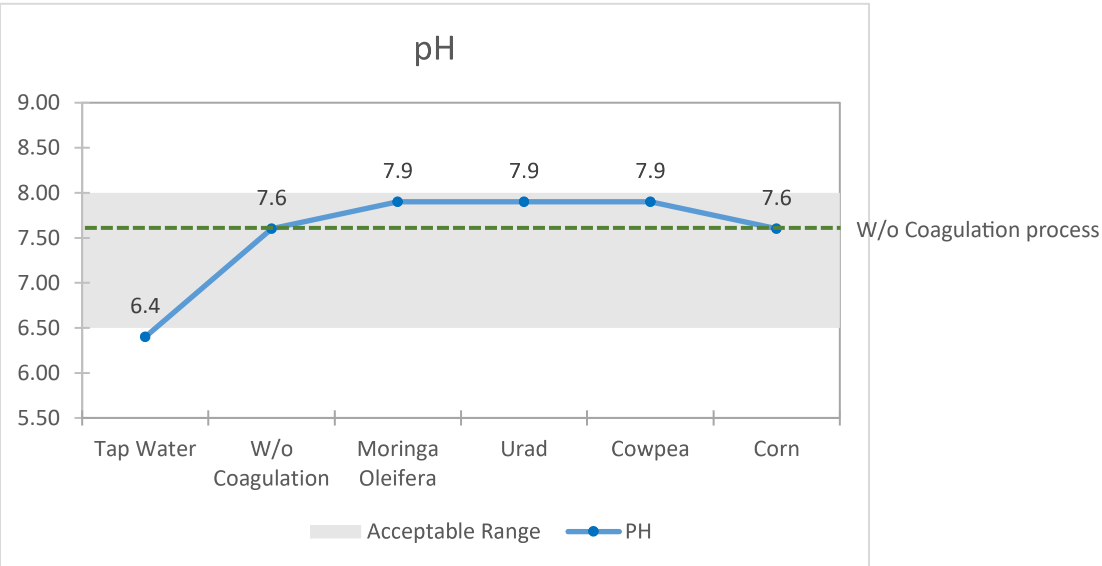

Figure 4: Observed pH, plotted for each of the coagulants after filtration process, the highlighted area shows the acceptable range.

These results show that the leguminous seed-based coagulants (Moringa Oleifera, Urad, and Cowpea) mildly increase the pH, due to the presence of basic organic compounds like proteins and alkaloids in the seed extracts. Most importantly, all pH values remained within the WHO guidelines, making the water safe for drinking.

These results are consistent with the findings of Chales et al. (2022), who reported that Moringa Oleifera stabilizes the pH. A review by Alazaiza et al. (2025) also confirms that natural coagulants preserve pH during treatment.

TDS

The WHO guidelines recommend that the TDS be below 300ppm for drinking water (WHO, 2008). Values above this affect taste gravely and thus are not suitable for human consumption. Values above this also signal that the water sample contains salts, minerals, or harmful contaminants like nitrates, arsenic, and lead, which can have adverse health effects. Salinity, which is also signalled by high TDS, can lead to severe diseases like cardiovascular disease, inflammation, and infection.

The water sample collected in the study showed a TDS of 335 before any treatment, which is marginally above the WHO limit. After basic filtration without coagulants, the TDS decreased only slightly to 314 ppm, indicating a limited impact from filtration alone.

These are plotted against the acceptable range in *Figure 5.*

The biggest improvement was shown by Moringa Oleifera, which reduced the TDS to well below the acceptable threshold. This indicates the usefulness of Moringa Oleifera in reducing TDS. Corn extracts were also extremely useful in lowering TDS. Urad and Cowpea, on the other hand, did not indicate a satisfactory level of TDS.

In this study, the TDS was measured using a conductivity-based meter, which estimates TDS by calculating the electrical conductivity of the water and then multiplying it by a factor of 0.5-0.7. This method doesn’t differentiate between truly dissolved ionic solids

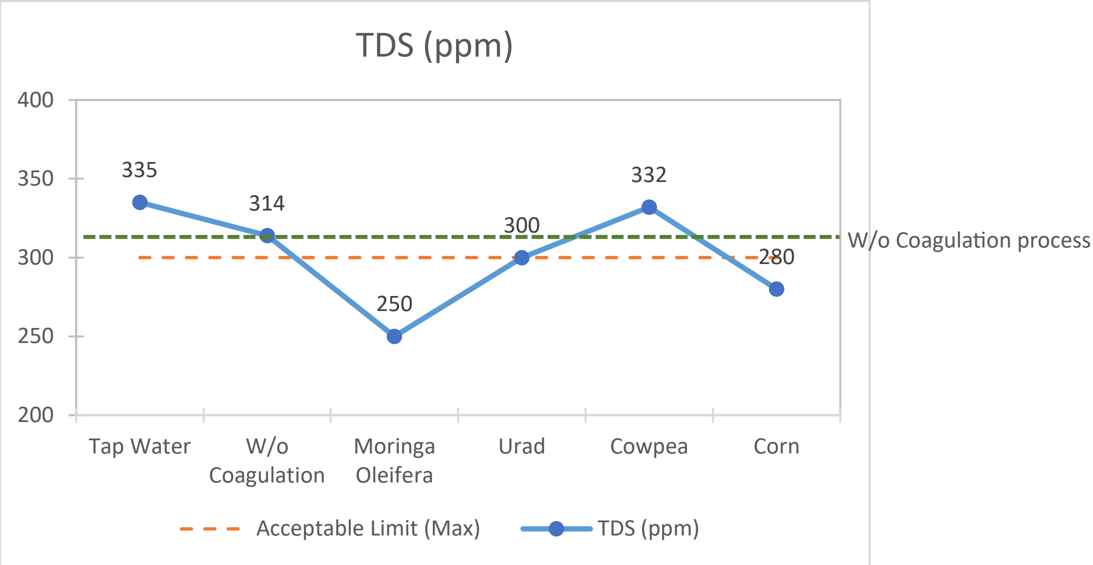

Figure 5 : Observed TDS (ppm), plotted for each of the coagulants after filtration process, the dotted line is the maximum acceptable limit**.**

and weakly charged colloids or organics (it is worth noting that weakly charged colloids or organics can also pose a harm to our health). As such, an EC-based TDS meter may overestimate TDS in the presence of weakly charged colloids or organics, and underestimate it when the water contains many uncharged dissolved solids (Rusydi, 2018). In contrast, the gravimetric method involves evaporating a known volume of water and weighing the dry residue, thus measuring only truly dissolved solids.

While the accuracy limitations of EC-based TDS meters are well recognized in scientific literature, in practice, especially in fieldwork and community-level testing, these devices are widely used because of their speed, portability, low cost, and reliability for relative comparisons (WHO, 2017; Rusydi, 2018). The gravimetric method is extremely tedious and requires days and perfect laboratory conditions to measure it, which was not possible. In the context of our study, this reliance on EC-based TDS measurements represents a limitation, as it may not fully reflect the true changes in dissolved solids following coagulation and filtration. But still, it does indicate the removal of potentially harmful weakly charged colloids or organics, indicating the usefulness of coagulants like Moringa Oleifera.

The TDS reduction observed in our study is attributed to the coagulants' ability to neutralize and bind charged colloidal or weakly dissolved organic matter, forming flocs which are then removed by sedimentation and filtration. These flocs no longer contribute to conductivity, leading to lower EC and thus lower TDS readings on the meter. This is supported by Sirbadgi et al. (2024), who observed up to 69.2% TDS reduction using plant-based coagulant.

Thus, while true ionic TDS (gravimetric) may remain partially unaffected, the reduction seen on a TDS meter (EC-based) is real and relevant, especially when considering the perceived quality and operational safety of drinking water. A significant reduction of TDS was seen after the filtration process, as it was reduced from 335ppm to 250ppm using Moringa Oleifera as a coagulant, which is also consistent with the reduction seen in literature. In sum, natural coagulants, especially Moringa Oleifera and Corn extract, display a vast reduction in TDS because of their ability to flocculate (cause fine suspended particles to clump together into aggregates or flocs, thus making them easier to remove) semi-dissolved and colloidal impurities. While they may not be considered truly dissolved, salts can be detected by gravimetric analysis; their effect on the water quality remains significant. The distinction between EC-based and gravimetric TDS should be recognized in both research and practical applications.

Chlorine

The WHO guidelines recommend that the Chlorines in potable water should be between 0.2-5.0 ppm. Chlorine was not detected in the original water sample, indicating that it is not present in the municipal tap water (in the area where the study was conducted). It was also not found in the water samples tested after coagulation and after filtration, signifying that coagulation doesn't lead to the addition of chlorine to the water.

Turbidity

The WHO recommends that the turbidity of potable water be below 5 NTU (Nephelometric Turbidity Unit). Anything above this value promotes the growth of microorganisms, which could be dangerous to health. Turbidity above 5 NTU also indicates that the water sample contains the presence of suspended solids and harmful pathogens that can be agents for diseases. (WHO, 2017).

In this study, the turbidity of the original tap water sample was observed at 14 NTU, which exceeds the WHO guideline and indicates a high level of harmful particulate matter. Filtration without coagulation reduced turbidity to 1 NTU, which showed the effectiveness of the multilayer filtration media in removing suspended solids.

These are plotted against the acceptable range in the *Figure 6.*

These results indicate that amongst all four coagulants used for filtration, Moringa Oleifera, and Cowpea were the most effective, as both displayed a turbidity of 1 NTU. The other two coagulants, Urad and Corn, displayed the turbidity values of 3 and 7 NTU, respectively. Urad was within the WHO guidelines, but the turbidity of Corn exceeds the WHO limit and therefore indicates incomplete removal of suspended matter.

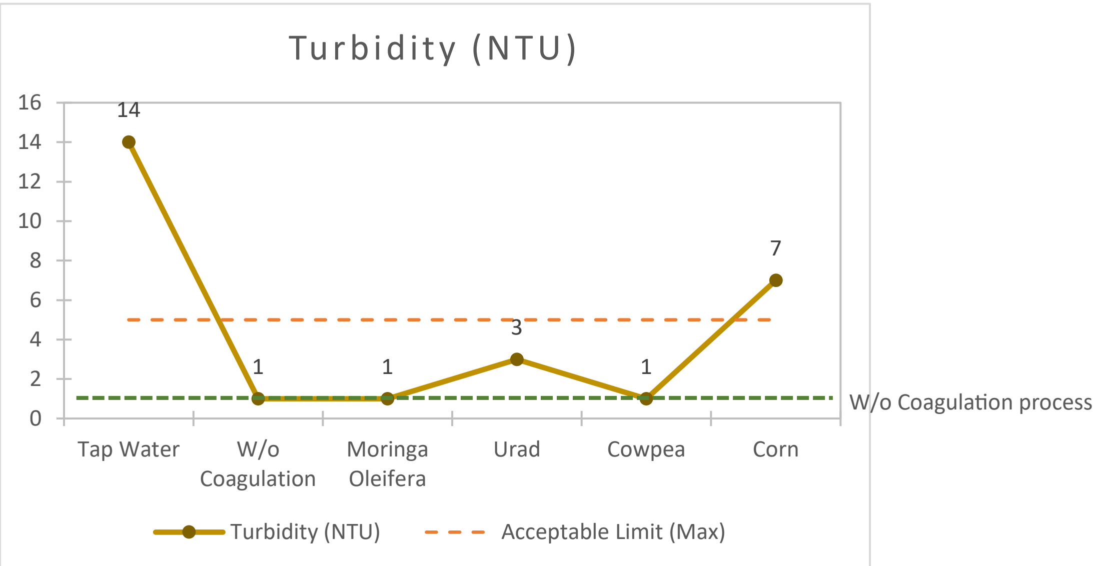

Figure 6 : Observed Turbidity (NTU), plotted for each of the coagulants after the filtration process, the dotted line is the maximum acceptable limit.

These findings are consistent with the results of Mangale et al. (2012), who reported that Moringa Oleifera seed extract reduced turbidity by over 90% in surface water samples, outperforming several other plant-based coagulants tested under similar conditions.

Total hardness

The World Health Organization (WHO) recommends that the total hardness of drinking water should be below 500 ppm as calcium carbonate, as higher levels can cause scaling in pipes, affect soap lathering, and contribute to taste changes (WHO, 2017). While hardness is not considered a direct health hazard, very high levels have been associated with, in extreme cases, kidney stone formation. (WHO, 2017)

In this study, the hardness of the tap water sample was found to be 250 ppm, which is below the acceptable limit. the hardness values appeared to increase after filtration without coagulation. This can likely be attributed to mineral leaching from the sand, gravel, or ceramic media, which may have released calcium and magnesium ions into the treated water. Making this process explicit highlights the importance of combining filtration with coagulation to prevent such unintended side effects.

These are plotted against the acceptable range in the *Figure 7.*

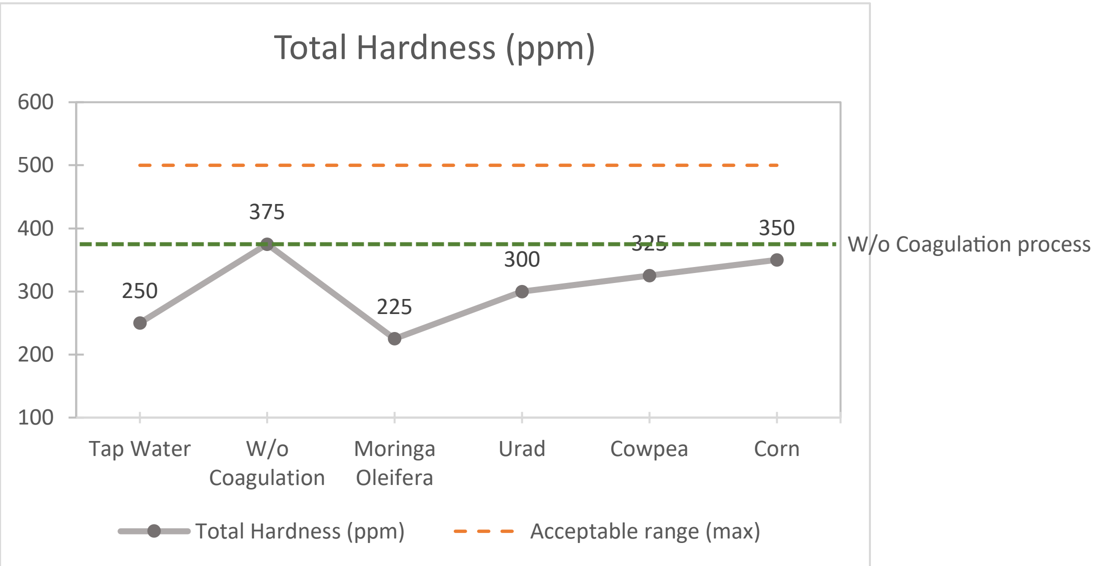

Figure 7 : Observed Total Hardness (ppm), plotted for each of the coagulates after filtration process, the dotted line is the max acceptable limit.

The results of this study show that Moringa Oleifera was the best in reducing the total hardness of water. Urad and Cowpea were also effective for this purpose. Corn was the least effective for this purpose. It is important to note that all values remained below the WHO limit and thus are safe for human consumption in the total hardness parameter.

Sulphate, Alkalinity, and Chloride

Sulphate ion concentration in drinking water is recommended to be less than 500 ppm, as anything beyond that can cause a bitter taste and gastrointestinal discomfort (WHO, 2017). The tap water contained 120 ppm, which increased to 160 ppm after filtration without coagulation, likely due to mineral leaching from the filter media. After coagulation, Moringa Oleifera and Cowpea showed higher sulphate levels at 180 ppm, whereas Urad and Corn maintained the original concentration at 120 ppm. All recorded sulphate levels were well below the WHO guideline value.

The recommended alkalinity range for potable water by the WHO is 20–200 ppm as $CaCO_3$, as it helps buffer pH and prevents rapid changes in acidity and alkalinity (WHO, 2017). The tap water sample measured well within this range at 75 ppm, remaining the same without coagulation after filtration. Moringa Oleifera and Urad both reduced it to 25ppm, and Cowpea increased it to 100 ppm, and Corn reduced it to 50 ppm. All the results observed were in the acceptable range.

The WHO recommends that the chloride in water should be less than 250 ppm, as it can cause issues with taste (WHO, 2017). In this study, the original tap water had a chloride level of 8ppm, which is well below the acceptable limit. Filtration with coagulants didn’t change this much. Among the coagulants, Moringa Oleifera showed an increase to 20 ppm, while Urad reduced it to 6 ppm. In comparison, Cowpea and Corn both resulted in 8 ppm, showing minimal changes in chloride content across most treatments, and showing that neither tap water nor water after coagulation contains any concerning amounts of chloride.

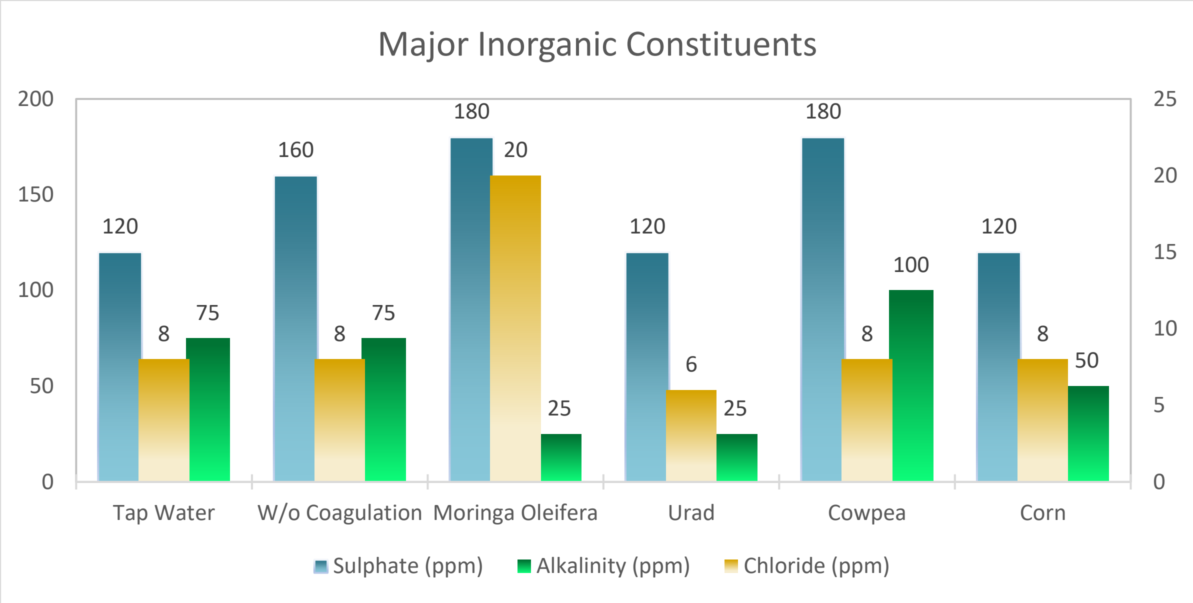

Figure 8 : Observed Sulphates (ppm) and Alkalinity (ppm), plotted on left Y axis, and Chlorides (ppm), plotted on right Y Axis, for each of the coagulants after filtration process.

Overall, the samples before and after the filtration of water were safe for human consumption on the parameters of chloride, alkalinity, and sulphate. Observed chlorides, alkalinity, and sulphates are plotted in the *Figure 8.*

Conclusion

This study evaluated the performance of four seed-based coagulants (Moringa Oleifera, Vigna Mungo (Urad), Vigna unguiculata (Cowpea), and Zea Mays (Corn)) when paired with a consistent DIY natural filtration system in improving the quality of rural tap water. It was tested across parameters, which included pH, TDS, turbidity, total hardness, chloride, alkalinity, and sulphate All the tested samples after filtration and coagulation were within the guidelines recommended by WHO, apart from Cowpea for TDS and Corn for Turbidity, which both exceeded the limits.

Moringa Oleifera was shown to be the best across all parameters, as it consistently outperformed the other coagulants tested. It achieved the highest reduction in TDS, turbidity, and hardness, while maintaining pH stability. The superior performance of *Moringa oleifera* compared to other natural coagulants can be explained by its unique water-soluble cationic proteins, which act as effective polyelectrolytes. These proteins neutralise negatively charged colloidal particles more efficiently, leading to faster flocculation and improved turbidity and contaminant reduction.

Cowpea also achieved strong turbidity removal but showed less improvement in TDS. Corn extract was moderately effective for TDS but underperformed in turbidity reduction. Urad provided balanced but less pronounced improvements across all the parameters.

The study shows that combining natural coagulants and a multi-layered natural filter can significantly improve water quality, offering a solution to the communities that lack centralized treatment infrastructure.

Future research

While the results of this paper are promising, several aspects need to be explored further to improve the practicality and scalability of this approach.

- Scalability of the System- future work needs to focus on making this design into a household modular design that can be capable of treating single household requirement of water per day.
- Fast and less tedious coagulation- the current method requires stirring for more than 60 minutes, which is impractical for large-scale or household use. Future research should aim to develop faster and more practical coagulation methods suitable for large-scale or household applications.
- Testing Across Diverse Water Sources- This study sampled water from a rural North Indian municipal tap supply. Additional trials should be conducted on various other types of water, like water near the sea, which would have more chloride content, water from downstream areas, or a highly turbid pond, and test which coagulants perform best in those waters.

- Pathogen removal assessment – The source of the water used in this study is municipal tap water, which comes from the river Ganga. Ganga water contains Bacteriophage, which removes bacteria and pathogens (Bahera et al., 2022). Further studies should test water sources with pathogens to evaluate the antimicrobial effectiveness of these coagulants.

Future research on these areas could help transition this approach from theory to practical, low-cost solutions. This could lead to a solution to the problem of unsafe water and lead to a world where all people realize their right to clean and potable water.

Acknowledgments

I would like to express my sincere gratitude to [redacted], who was my mentor throughout this journey and provided invaluable insight, feedback, and knowledge. I am also extremely thankful to [redacted], who was [redacted], and has helped me immensely with my paper through his constructive feedback, unique ideas, and encouragement throughout the whole process. Special thanks are also extended to the team over at [redacted] for providing their lab as well as materials, which enabled me to conduct all experiments.

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Appendix 1

Table 1 summarizes the results observed for the tested parameters of raw water and the filtrates after the coagulation process. The corresponding WHO guidelines are also provided for the better understanding of the improvements in the water quality achieved.

Table 1

Results of Water Quality Parameters Before and After Coagulation Treatment

	WHO Guidelines	Tap Water	W/o Coagulation	Moringa Oleifera	Urad	Cowpea	Corn
pH	6.5-8.0	6.4	7.6	7.9	7.9	7.9	7.6
TDS (ppm)	<300	335	314	250	300	332	280
Chlorine (ppm)	0.2-5.0	ND	ND	ND	ND	ND	ND
Turbidity (NTU)	<5	14	1	1	3	1	7
Total Hardness (ppm)	<500	250	375	225	300	325	350
Sulphate (ppm)	<500	120	160	180	120	180	120
Alkalinity (ppm)	20-200	75	75	25	25	100	50
Chloride (ppm)	<250	8	8	20	6	8	8
ND: Not detected							

~~Comparative Analysis of Natural Coagulants, Moringa Oleifera, Urad, Cowpea, and Corn, for Rural Water Treatment~~

Optimising Rural Water Quality Using Indigenous Plant-Based Coagulants: A Comparative Analysis

[name redacted by Managing Editor]
[school redacted by Managing Editor]
[email redacted by Managing Editor]

Abstract

Access to potable water is a basic human right and remains a critical challenge, particularly in regions where the river water isn't clean~~. This study presents a comparative analysis of different seed-based natural coagulants~~This study presents a comparative analysis of four seed-based natural coagulants (*Moringa* ~~Oleifera~~, *Vigna Mungo* (Urad), *Vigna Unguiculata* (Cowpea), and *Zea Mays* (Corn)) combined with a consistent natural filter for purifying rural tap water. Recent research has highlighted the potential of low-cost, naturally occurring materials as effective solution~~s~~ for rural water purification. This study addresses the gap in existing literature by testing multiple coagulants under consistent filtration conditions to determine which is the best-performing coagulant.

To test this, a consistent multilayer natural filtration prototype was used, with a single source of rural municipal tap water sample, which was first treated with each of the four coagulants and then passed through the filter. Turbidity, TDS, pH, sulphate, chlorine, chloride, alkalinity, and total hardness were measured for the sampled water, after the coagulation stage and after filtration, to assess the performance of the coagulants.

The results showed that Moringa Oleifera consistently outperformed other coagulants, achieving the greatest reductions in TDS (Total Dissolved Solids), turbidity, and hardness while maintaining pH stability. Cowpea was found to be effective for the reduction in turbidity, and Corn extract showed moderate TDS reduction. Urad exhibited average performance in

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all tested parameters. All treated samples, except for Corn in the case of turbidity and Cowpea in the case of TDS, met the WHO (World Health Organization) guidelines for safe drinking water.

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To test this, a consistent multilayer natural filtration prototype was used, with a single source of rural municipal tap water sample, which was first treated with each of the four coagulants and then passed through the filter. Turbidity, TDS, pH, sulphate, chlorine, chloride, alkalinity, and total hardness were measured for the sampled water, after the coagulation stage and after filtration, to assess the performance of the coagulants.

Keywords: Water Science, Water Resources Management, Rural Water Purification, Natural Coagulants, Multistage Filtration

Introduction

Access to clean drinking water remains a huge challenge, especially in many rural areas where getting an expensive filter isn't feasible. In many regions of India, sewage systems are dysfunctional. According to recent studies, rivers like the Yamuna, which serve as water sources for millions, are severely polluted due to untreated sewage, industrial effluents, and agricultural runoff, resulting in high BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) levels, low dissolved oxygen, and unsafe microbial contamination (Srivastava et al., 2025). Considering the poor quality of sewage treatment and the large population without access to safe water, it becomes crucial to develop a cheap and do-it-yourself (DIY) method for water purification.

Filtration works in two steps: first, particles move towards the filter (transportation), and then they attach to the filter surface (attachment). Particles move through the water using processes like diffusion, interception, or settling, depending on their size (O'Melia & Stumm, 1967). Small particles are best removed by diffusion, while larger particles settle or get caught as they pass through the filter (Yao et al., 1971). These particles need to be treated chemically, using coagulants. This helps them form larger chunks of impurities,

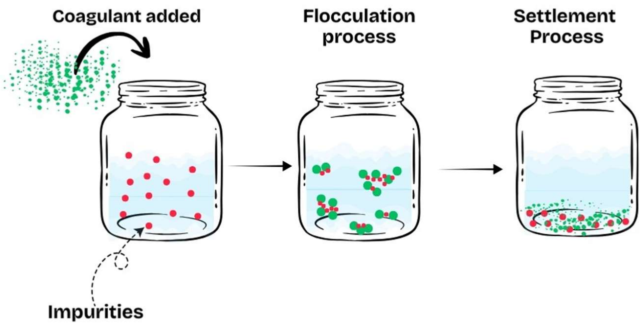

Figure 1 : *Formation of larger chunks of impurities during coagulation process. Adapted from: Beyene et al (2016).*

called coagulates, which makes them easier to trap in the filter and remove from the water (Ntibrey et al., 2020), as shown in the *Figure 1*.

This is central to understanding how different coagulants like Moringa Oleifera affect the properties of the water after it is filtered. This study compares natural coagulants by first coagulating a consistent sample of raw water taken from a tap in a rural region and then filtering the same water through a consistent multi-stage natural filter.

Water quality is defined by a range of physico-chemical parameters that determine its suitability for human consumption and ecological Forbalance improving various quality parameters of water, natural filters and coagulants play an extremely important role. In this study, vital parameters like Total Dissolved Solids (TDS), pH, turbidity, sulphates, chlorine, chloride, alkalinity, and total hardness were tested. Total Dissolved Solids (TDS) indicate the concentration of inorganic salts and directly affect taste and potability. pH reflects the acidity or alkalinity of water, with extreme deviations harming health. Turbidity measures suspended particles, which can shield microorganisms from disinfection and signal pollution. Sulphates, chlorine, and chloride, while permissible in small amounts, may cause gastrointestinal discomfort, corrosivity, or unpleasant taste when elevated Alkalinity governs the buffering capacity of water against pH fluctuations, and total hardness, driven by calcium and magnesium levels, influences scaling, taste, and potential health effects. In this study, changes in these parameters were systematically examined, .

These coagulants aggregate suspended impurities in water, which makes it easier to remove them during the filtration process. This is the reason why both Turbidity and TDS are reduced after coagulation, as noted in Sirbadgi et al., 2024, where TDS and Turbidity were both reduced ~~by 69.2% and 92.7% respectively~~. The process also stabilized pH levels, neutralizing acidic or basic components to bring the water closer to neutral conditions, as demonstrated with Moringa Oleifera seed powder. The process of coagulation reduces the quantum of harmful contaminants like chloride and sulphates, and improves hardness and alkalinity (Nzeyimana & Mary, 2024). "The process of coagulation followed by filtration ~~The process of filtration followed by coagulation is an~~ Is an effective procedure to make water safer for drinking.

Several studies have explored the development of low-cost filtration systems for rural communities. They often use simple, affordable materials such as sand, activated charcoal, ceramic discs, and rice husk ash (Lakhote et al., 2016; Henry Michael et al., 2013). While most focus on physical or adsorptive filtration, only a smaller set of researchers has incorporated naturally available coagulants to enhance performance. Chauhan et al. (2015) reported the significant coagulation and antimicrobial properties of Moringa Oleifera, Vigna Mungo (Urad), Vigna Unguiculata (Cowpea), and Zea Mays (Corn). It showed up to 92% microbial count reduction. ~~Ntibrey et al. (2020) showed that combining Moringa Oleifera with a filter achieved 98% turbidity removal and 99% elimination of E. coli and coliform bacteria.~~

Despite these promising results, there remains a lack of comparative studies evaluating different natural coagulants under consistent filtration setups. This study addresses that gap by testing four seed-based coagulants—Moringa Oleifera, Urad, Cowpea, and Corn—under identical experimental conditions, paired with a single multi-stage filter made from natural materials.

The objective of the study is to identify which of the natural coagulants— Moringa Oleifera, Urad, Cowpea or Corn—performs best in improving water quality. The raw water sample was coagulated and filtered. The filtered water was tested for total dissolved solids

(TDS), pH, turbidity, sulphate (AE 209), chlorine (AE 246), chloride (AE 213), alkalinity (AE 214), and total hardness (AE 211). These tests were performed on raw water, on water after coagulation, and on final filtered water to determine the effect of each process and assess the effectiveness of each coagulant.

~~The result from this study exhibited that amongst the four tested coagulants, Moringa Oleifera showed the maximum improvement in all the parameters tested, achieving the highest reductions in TDS, turbidity, and hardness, while maintaining pH. Cowpea also performed strongly in turbidity removal but was less effective in lowering TDS. Corn extract showed moderate TDS reduction but underperformed in turbidity removal, and Urad displayed balanced yet less pronounced improvements across the parameters. All treatments, except for Corn for turbidity, produced water that met WHO guidelines for safe drinking water.~~

This paper is structured as follows: Section 2 describes the experimental setup, materials, and methodology. Section 3 depicts the results of each coagulant. Section 4 concludes the study and depicts the main findings, limitations of our study, and future research directions.

Methods and Materials

Materials

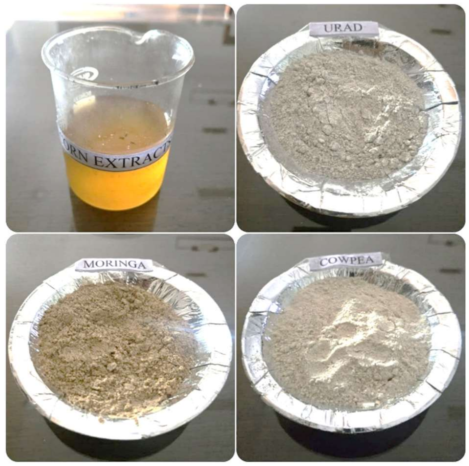

Figure 2: Four coagulants used for the coagulation. Corn Extract, Urad, Moringa Oleifera, and Cowpea.

A consistent, natural, multi-layered DIY filter was used to compare the coagulants. First, the Coagulant pre-treatment was done, followed by a multi-stage natural filter. The materials used were as follows:

1. Coagulant Pretreatment

Before filtration, raw water was treated with one of the four natural coagulants: Moringa Oleifera, Urad (Vigna Mungo), Cowpea (Vigna Unguiculata), and Corn (Zea Mays) seed extracts. These plant-based substances act as flocculants, helping suspended particles and microorganisms clump together (Madsen et al., 1987). The study evaluates which of these coagulants is the most efficient. The coagulants were chosen as they were easily available, farmed locally, and cost-effective. The seeds were ground using a household mixer grinder to achieve a fine powder, as depicted in the *Figure 2*.

2. Filter Structures

After coagulant pretreatment, water passes through the following layers, arranged from top to bottom (as shown in *Fig. 3*):

Cotton Pre-filter. A clean cloth layer was used to trap coarse sediment and large debris before water entered the main system. While not effective for microbial removal on its own, it plays a vital role in reducing turbidity. Cloth filters have been shown to significantly

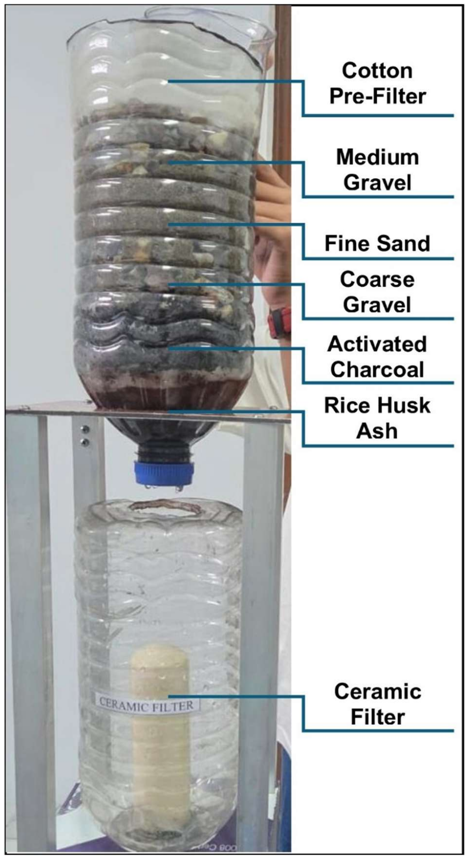

Figure 3 : A consistent, natural, multi-layered DIY filter was used to compare the water after coagulation.

reduce microbial load by capturing carriers of waterborne pathogens and to lower cholera incidence in areas where boiling water is not possible (Colwell et al., 2003).

Sand–Gravel Filter. The mechanical filtration stage includes:

Medium Gravel. Distributes water evenly across the layer.

Fine Sand. Traps dirt and suspended particles.

Coarse Gravel. Supports the filter structure and aids drainage.

This configuration removes most visible impurities and reduces turbidity before water passes into finer filtration layers. Its effectiveness depends on the grain size (Lakhote et al., 2016).

Activated Charcoal Filter. Activated charcoal was included for its ability to trap pollutants and remove odours, colours, and synthetic impurities from water. (Ajaybhaskar Reddy et al., 2023).

Rice Husk Ash Layer. Produced from finely burned and sifted rice husks, this layer is rich in amorphous silica. Modified rice husk ash has been shown to remove up to 98% of arsenic from contaminated water (Javed et al., 2022).

Ceramic Filter Unit. A ceramic filter was used as the final filter media, serving as a fine-pore barrier capable of reducing turbidity and removing 77–96% of E. coli from water (Bulta & Michael, 2019).

3. Testing Parameters

For raw water, coagulated water, and final filtered water, the following parameters were measured: turbidity, total dissolved solids (TDS), pH, sulphate (AE 209), chlorine (AE 246), chloride (AE 213), alkalinity (AE 214), and total hardness (AE 201 and AE 211).

The equipment used to test various parameters included:

1. pH- Demeteries pH testing kit.
2. TDS- KENT Digital TDS Meter.
3. Chlorine- (AE 246) Aquasol.
4. Turbidity - Demeteries turbidity testing kit.
5. Total Hardness - (AE 211) Aquasol.
6. Sulphates- (AE 209) Aquasol.
7. Alkalinity- (AE 214) Aquasol.
8. Chloride (AE 213) Aquasol.

The apparatus used for coagulation and mixing was a Remi RQ-140/DE Homogeniser.

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Methods

1. Sampling

The water sample was collected from a small village named Dadupur in Haridwar districtn in Indiaearby rural area, sourced from the municipal tap supply. It was selected as it reflects the general water quality available in most rural areas and is considered to have higher contamination levels.

The procedure was as follows:

2. *Coagulation.*

For each trial, the water sample was placed in a clean container and treated with the powdered form of the assigned coagulant at a concentration of 2g/l. The dosage of 2 g/L was selected based on prior studies where similar natural coagulant concentrations demonstrated effective turbidity and contaminant reduction while maintaining water safety (Ntibrey et al., 2020). The mixture was stirred continuously for 60 minutes using a homogeniser mixer to ensure an effective coagulation process. It was then left undisturbed for 30 minutes to allow floc (aggregate of impurities) formation and sedimentation. Following the settling period, it was carefully passed through the multi-stage filtration unit.

3. *Filtration*.

After the coagulation, the clear supernatant was passed through the multistage filtration unit described in the materials section above. The filtration was conducted without any external force and only under gravitational flow; the average processing time for each sample was about 30 minutes. Between trials, the filtration unit was rinsed with distilled water to avoid any cross-contamination.

4. *Testing*.

The tests for all the parameters were performed on the raw water sample, on the water after coagulation, and on the water after filtration. The filtered raw water without coagulation was also tested. All the tests were repeated three times, and the average figures were recorded. All tests were carried out according to the guidelines provided in the respective testing kits and performed under controlled laboratory conditions.

For this study WHO benchmarks for all parameters were used to determine the suitability of the water quality as The World Health Organization (WHO) drinking water quality standards provide globally recognized limits for safe and acceptable water, covering key parameters such as TDS, pH, turbidity, sulphates, chloride, and hardness. Since these guidelines are widely applicable across regions where national or regional standards may not directly apply, they serve as the primary reference point in this study for assessing the suitability of water for human consumption.

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Results and discussion

pH

The World Health Organization (WHO) recommends that the pH of drinking water should be between 6.5 to 8.0. The values outside this range can cause corrosion, scaling, or unwanted taste (WHO, 2008). The water with pH values below 4 or above 11 causes corrosive injury to the mouth, throat, and digestive tract; it can also be acutely toxic.

The results in this study indicated a pH of 6.4 for tap water, which is just below the acceptable minimum. After filtration without any coagulation process, the pH increased to 7.6, indicating that the multilayer filtration process itself helps neutralize the slight acidity.

A slight increase in pH was also observed in the filtrate of the coagulated water. ~~The following results were observed.~~ These are plotted against the acceptable range in the *Figure 4*

~~Moringa Oleifera: 7.9~~

- ~~Urad (Vigna Mungo): 7.9~~
- ~~Cowpea (Vigna Unguiculata): 7.9~~
- ~~Corn (Zea Mays): 7.6~~

These results show that the leguminous seed-based coagulants (Moringa Oleifera, Urad, and Cowpea) mildly increase the pH, due to the presence of basic organic compounds like proteins and alkaloids in the seed extracts. Most importantly, all pH values remained within the WHO guidelines, making the water safe for drinking.

These results are consistent with the findings of Chales et al. (2022), who reported that Moringa Oleifera stabilizes the pH. A review by Alazaiza et al. (2025) also confirms that natural coagulants preserve pH during treatment.

Figure 4: Observed pH, plotted for each of the coagulants after filtration process, the highlighted area shows the acceptable range.

TDS

The WHO guidelines recommend that the TDS be below 300ppm for drinking water (WHO, 2008). Values above this affect taste gravely and thus are not suitable for human consumption. Values above this also signal that the water sample contains salts, minerals, or harmful contaminants like nitrates, arsenic, and lead, which can have adverse health effects. Salinity, which is also signalled by high TDS, can lead to severe diseases like cardiovascular disease, inflammation, and infection.

The water sample collected in the study showed a TDS of 335 before any treatment, which is marginally above the WHO limit. After basic filtration without coagulants, the TDS decreased only slightly to 314 ppm, indicating a limited impact from filtration alone.

~~The following TDS results were observed in the filtrate of the coagulated water.~~ These are plotted against the acceptable range in the *Figure 5.*

- ~~Moringa Oleifera: 250 ppm.~~
- ~~Urad (Vigna Mungo): 300 ppm.~~
- ~~Cowpea (Vigna Unguiculata): 332 ppm.~~
- ~~Corn extract: 280 ppm.~~

W/o Coagulation process

The biggest improvement was shown by Moringa Oleifera, which reduced the TDS to well below the acceptable threshold. This indicates the usefulness of Moringa Oleifera in reducing TDS. Corn extracts were also extremely useful in lowering TDS. Urad and Cowpea, on the other hand, did not indicate a satisfactory level of TDS.

In this study, the TDS was measured using a conductivity-based meter, which estimates TDS by calculating the electrical conductivity of the water and then multiplying it by a factor of 0.5-0.7. This method doesn't differentiate between truly dissolved ionic solids and weakly charged colloids or organics (it is worth noting that weakly charged colloids or organics can also pose a harm to our health). As such, an EC-based TDS meter may overestimate TDS in the presence of weakly charged colloids or organics, and underestimate it when the water contains many uncharged dissolved solids (Rusydi, 2018). In contrast, the gravimetric method involves evaporating a known volume of water and weighing the dry residue, thus measuring only truly dissolved solids.

While the accuracy limitations of EC-based TDS meters are well recognized in scientific literature, in practice, especially in fieldwork and community-level testing, these devices are widely used because of their speed, portability, low cost, and reliability for relative comparisons (WHO, 2017; Rusydi, 2018). The gravimetric method is extremely

W/o Coagulation process

Figure 5 : Observed TDS (ppm), plotted for each of the coagulants after filtration process, the dotted line is the maximum acceptable limit.

tedious and requires days and perfect laboratory conditions to measure it, which was not possible. In the context of our study, this reliance on EC-based TDS measurements represents a limitation, as it may not fully reflect the true changes in dissolved solids following coagulation and filtration. But still, it does indicate the removal of potentially harmful weakly charged colloids or organics, indicating the usefulness of coagulants like Moringa Oleifera.

The TDS reduction observed in our study is attributed to the coagulants' ability to neutralize and bind charged colloidal or weakly dissolved organic matter, forming flocs which are then removed by sedimentation and filtration. These flocs no longer contribute to conductivity, leading to lower EC and thus lower TDS readings on the meter. This is supported by Sirbadgi et al. (2024), who observed up to 69.2% TDS reduction using plant-based coagulant.

Thus, while true ionic TDS (gravimetric) may remain partially unaffected, the reduction seen on a TDS meter (EC-based) is real and relevant, especially when considering the perceived quality and operational safety of drinking water. A significant reduction of TDS was seen after the filtration process, as it was reduced from 335ppm to 250ppm using Moringa Oleifera as a coagulant, which is also consistent with the reduction seen in literature. In sum, natural coagulants, especially Moringa Oleifera and Corn extract, display a vast reduction in TDS because of their ability to flocculate (cause fine suspended particles to clump together into aggregates or flocs, thus making them easier to remove) semi-dissolved and colloidal impurities. While they may not be considered truly dissolved, salts can be detected by gravimetric analysis; their effect on the water quality remains significant. The distinction between EC-based and gravimetric TDS should be recognized in both research and practical applications.

Chlorine

The WHO guidelines recommend that the Chlorines in potable water should be between 0.2-5.0 ppm. Chlorine was not detected in the original water sample, indicating that it is not present in the municipal tap water (in the area where the study was conducted). It was also not found in the water samples tested after coagulation and after filtration, signifying that coagulation doesn’t lead to the addition of chlorine to the water.

Turbidity

The WHO recommends that the turbidity of potable water be below 5 NTU (Nephelometric Turbidity Unit). Anything above this value promotes the growth of microorganisms, which could be dangerous to health. Turbidity above 5 NTU also indicates that the water sample contains the presence of suspended solids and harmful pathogens that can be agents for diseases. (WHO, 2017).

In this study, the turbidity of the original tap water sample was observed at 14 NTU, which exceeds the WHO guideline and indicates a high level of harmful particulate matter. Filtration without coagulation reduced turbidity to 1 NTU, which showed the effectiveness of the multilayer filtration media in removing suspended solids.

W/o Coagulation process

Figure 6 : Observed Turbidity (NTU), plotted for each of the coagulants after the filtration process, the dotted line is the maximum acceptable limit.

The following turbidity results were observed in the filtrate of the coagulated water. These are plotted against the acceptable range in the *Figure 6.*

- Moringa Oleifera: 1 NTU
- Urad (Vigna Mungo): 3 NTU
- Cowpea (Vigna Unguiculata): 1 NTU
- Corn (Zea Mays): 7 NTU

These results indicate that amongst all four coagulants used for filtration, Moringa Oleifera, and Cowpea were the most effective, as both displayed a turbidity of 1 NTU. The other two coagulants, Urad and Corn, displayed the turbidity values of 3 and 7 NTU, respectively. Urad was within the WHO guidelines, but the turbidity of Corn exceeds the WHO limit and therefore indicates incomplete removal of suspended matter.

These findings are consistent with the results of Mangale et al. (2012), who reported that Moringa Oleifera seed extract reduced turbidity by over 90% in surface water samples, outperforming several other plant-based coagulants tested under similar conditions.

Total hardness

The World Health Organization (WHO) recommends that the total hardness of drinking water should be below 500 ppm as calcium carbonate, as higher levels can cause scaling in pipes, affect soap lathering, and contribute to taste changes (WHO, 2017). While hardness is not considered a direct health hazard, very high levels have been associated with, in extreme cases, kidney stone formation. (WHO, 2017)

In this study, the hardness of the tap water sample was found to be 250 ppm, which is below the acceptable limit. the hardness values appeared to increase after filtration without coagulation. This can likely be attributed to mineral leaching from the sand, gravel, or ceramic media, which may have released calcium and magnesium ions into the treated water. Making this process explicit highlights the importance of combining filtration with coagulation to prevent such unintended side effects. Filtration without coagulation, the

Figure 7 : Observed Total Hardness (ppm), plotted for each of the coagulates after filtration process, the dotted line is the max acceptable limit.

~~hardness increased to 375 ppm, which is likely because of the leaching of minerals such as calcium and magnesium from the filtration media. This increase is also not concerning since it is very well below the WHO guidelines.~~

~~The following Total Hardness results were observed in the filtrate of the coagulated water.~~ These are plotted against the acceptable range in the *Figure 7.*

- ~~Moringa Oleifera: 225 ppm~~
- ~~Urad (Vigna Mungo): 300 ppm~~
- ~~Cowpea (Vigna Unguiculata): 325 ppm~~
- ~~Corn (Zea Mays): 350 ppm~~

The results of this study show that Moringa Oleifera was the best in reducing the total hardness of water. Urad and Cowpea were also effective for this purpose. Corn was the least effective for this purpose. It is important to note that all values remained below the WHO limit and thus are safe for human consumption in the total hardness parameter.

Sulphate, Alkalinity, and Chloride

W/o Coagulation process

Sulphate ion concentration in drinking water is recommended to be less than 500 ppm, as anything beyond that can cause a bitter taste and gastrointestinal discomfort (WHO, 2017). The tap water contained 120 ppm, which increased to 160 ppm after filtration without coagulation, likely due to mineral leaching from the filter media. After coagulation, Moringa Oleifera and Cowpea showed higher sulphate levels at 180 ppm, whereas Urad and Corn maintained the original concentration at 120 ppm. All recorded sulphate levels were well below the WHO guideline value.

The recommended alkalinity range for potable water by the WHO is 20–200 ppm as $CaCO_3$, as it helps buffer pH and prevents rapid changes in acidity and alkalinity (WHO, 2017). The tap water sample measured well within this range at 75 ppm, remaining the same without coagulation after filtration. Moringa Oleifera and Urad both reduced it to 25ppm, and Cowpea increased it to 100 ppm, and Corn reduced it to 50 ppm. All the results observed were in the acceptable range.

The WHO recommends that the chloride in water should be less than 250 ppm, as it can cause issues with taste (WHO, 2017). In this study, the original tap water had a chloride level of 8ppm, which is well below the acceptable limit. Filtration with coagulants didn't change this much. Among the coagulants, Moringa Oleifera showed an increase to 20 ppm, while Urad reduced it to 6 ppm. In comparison, Cowpea and Corn both resulted in 8 ppm, showing minimal changes in chloride content across most treatments, and showing that neither tap water nor water after coagulation contains any concerning amounts of chloride.

Overall, the samples before and after the filtration of water were safe for human consumption on the parameters of chloride, alkalinity, and sulphate. Observed chlorides, alkalinity, and sulphates are plotted in the *Figure 8.*

Figure 8 : Observed Sulphates (ppm) and Alkalinity (ppm), plotted on left Y axis, and Chlorides (ppm), plotted on right Y Axis, for each of the coagulants after filtration process.

Conclusion

This study evaluated the performance of four seed-based coagulants (Moringa Oleifera, Vigna Mungo (Urad), Vigna unguiculata (Cowpea), and Zea Mays (Corn)) when paired with a consistent DIY natural filtration system in improving the quality of rural tap water. It was tested across parameters, which included pH, TDS, turbidity, total hardness, chloride, alkalinity, and sulphate (summarized in *Table 1, Appendix 1*). All the tested samples after filtration and coagulation were within the guidelines recommended by WHO, apart from Cowpea for TDS and Corn for Turbidity, which both exceeded the limits.

Moringa Oleifera was shown to be the best across all parameters, as it consistently outperformed the other coagulants tested. It achieved the highest reduction in TDS, turbidity, and hardness, while maintaining pH stability. The superior performance of *Moringa oleifera* compared to other natural coagulants can be explained by its unique water-soluble cationic proteins, which act as effective polyelectrolytes. These proteins neutralise negatively charged colloidal particles more efficiently, leading to faster flocculation and improved turbidity and contaminant reduction.

Cowpea also achieved strong turbidity removal but showed less improvement in TDS. Corn extract was moderately effective for TDS but underperformed in turbidity reduction. Urad provided balanced but less pronounced improvements across all the parameters.

The study shows that combining natural coagulants and a multi-layered natural filter can significantly improve water quality, offering a solution to the communities that lack centralized treatment infrastructure.

Future research

While the results of this paper are promising, several aspects need to be explored further to improve the practicality and scalability of this approach.

- Scalability of the System- future work needs to focus on making this design into a household modular design that can be capable of treating single household requirement of water per day.
- Fast and less tedious coagulation- the current method requires stirring for more than 60 minutes, which is impractical for large-scale or household use. Future research should aim to develop faster and more practical coagulation methods suitable for large-scale or household applications.
- Testing Across Diverse Water Sources- This study sampled water from a rural North Indian municipal tap supply. Additional trials should be conducted on various other types of water, like water near the sea, which would have more chloride content, water from downstream areas, or a highly turbid pond, and test which coagulants perform best in those waters.
- Pathogen removal assessment – The source of the water used in this study is municipal tap water, which comes from the river Ganga. Ganga water contains Bacteriophage, which removes bacteria and pathogens (Bahera et al., 2022).

Further studies should test water sources with pathogens to evaluate the antimicrobial effectiveness of these coagulants.

Future research on these areas could help transition this approach from theory to practical, low-cost solutions. This could lead to a solution to the problem of unsafe water and lead to a world where all people realize their right to clean and potable water.

Acknowledgments

I would like to express my sincere gratitude to Dr. Devin Carroll from UPenn, who was my mentor throughout this journey and provided invaluable insight, feedback, and knowledge. I am also extremely thankful to Mr. Kieran Tait from Bristol University, who was my Teaching Assistant, and has helped me immensely with my paper through his constructive feedback, unique ideas, and encouragement throughout the whole process. Special thanks are also extended to the team over at The Rishabh Velveleen for providing their lab as well as materials, which enabled me to conduct all experiments.

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Appendix 1

Table 1 summarizes the results observed for the tested parameters of raw water and the filtrates after the coagulation process. The corresponding WHO guidelines are also provided for the better understanding of the improvements in the water quality achieved.

Table 1

Results of Water Quality Parameters Before and After Coagulation Treatment

	WHO Guidelines	Tap Water	W/o Coagulation	Moringa Oleifera	Urad	Cowpea	Corn
pH	6.5-8.0	6.4	7.6	7.9	7.9	7.9	7.6
TDS (ppm)	<300	335	314	250	300	332	280
Chlorine (ppm)	0.2-5.0	ND	ND	ND	ND	ND	ND
Turbidity (NTU)	<5	14	1	1	3	1	7
Total Hardness (ppm)	<500	250	375	225	300	325	350
Sulphate (ppm)	<500	120	160	180	120	180	120
Alkalinity (ppm)	20-200	75	75	25	25	100	50
Chloride (ppm)	<250	8	8	20	6	8	8

ND: Not detected

Subject: Revised Manuscript Submission – Response to Reviewer Feedback

Dear Referee 1,

Thank you very much for your constructive and detailed feedback on my manuscript. I have carefully considered each of your suggestions and revised the paper accordingly. A summary of the changes made is outlined below:

1. **Introduction suggestions:** I have amended the paper and added a paragraph in the introduction explaining what each parameter represents and the consequences of not adhering to WHO guidelines.
2. **Methods:** I have justified the use of 2 g/L coagulant dosage and added a supporting citation. I have also clarified that the mixer used was a homogeniser mixer, and included the model in the materials section for precision.
3. **Discussion of results:** I have expanded the discussion to explain more clearly why *Moringa oleifera* outperformed the other coagulants, and why hardness levels increased when water was passed through the filter without coagulation.
4. **Grammar and Language:** I have carefully considered your suggestions and corrected the grammar and language throughout the manuscript.
5. **Formatting:** I have fixed the formatting error as recommended.

I believe these revisions have significantly improved the clarity and strength of the manuscript. Thank you once again for your time, effort, and guidance in reviewing my work.

Sincerely,
[name redacted by Managing Editor]

Subject: Revised Manuscript Submission – Response to Reviewer Feedback

Dear Referee 2,

Thank you very much for your detailed and constructive feedback on my manuscript. I have carefully implemented your recommendations, and the revisions made are summarized below:

1. **Title:** I have revised the title in accordance with your suggestion.
2. **Abstract:** I have incorporated all the suggestions you provided to improve clarity and conciseness.
3. **Introduction:** I have added a paragraph explaining what each parameter represents and the consequences of not adhering to WHO guidelines. I have removed direct result statements and the results paragraph previously included in the introduction. Additionally, I have specified the exact location from which the water samples were collected and clarified why WHO standards were chosen as the preferred benchmark over others.
4. **Methods and Materials:** I have corrected the formatting issues in this section.
5. **Results:** I have removed redundant numbers already presented in the charts, fixed formatting issues, and removed the line "(summarised in Table 1, Appendix 1)."

I believe these revisions have addressed all of your comments and strengthened the overall clarity and quality of the paper. Thank you again for your time, effort, and valuable guidance in reviewing my work.

Sincerely,
[name redacted by Managing Editor]

This is excellent work, and the revisions have brought it to a very high standard. The following points are not required for acceptance but are offered as constructive critiques to help you further refine your scientific thinking and writing for future projects.

1. Quantifying the "Best" Performer:
While you conclusively state that Moringa is the best performer, you could strengthen this claim by adding a layer of quantitative analysis. A simple, effective method would be to “create a scoring system”. For each parameter (TDS, Turbidity, Hardness, etc.), assign a score based on the percentage improvement or simply rank the coagulants from 1 (best) to 4 (worst) for that parameter. Summing these scores would provide a single, quantitative metric confirming Moringa's overall superiority. This moves the conclusion from qualitative ("it was the best") to quantitative ("it had the highest cumulative performance score of X"). This is a powerful technique for comparative studies.

2. Deepening the "Why" in the Discussion:
You've made a great start by mentioning Moringa's cationic proteins. You can deepen this further by speculating on why the other coagulants performed as they did. For instance:
-Cowpea & Turbidity: Why was Cowpea good at turbidity removal but poor at TDS reduction? This might suggest its active compounds are effective at binding large, suspended particles (affecting turbidity) but less effective at neutralizing the charged colloids that influence EC-based TDS.
-Corn & TDS: Conversely, why was Corn moderate for TDS but poor for turbidity? Perhaps its extracts are better at binding the specific colloids in your water sample without forming large, settleable flocs.

3. Refining the "Future Research" Section:
Your future research directions are good and practical. To make them even stronger, consider making them more specific and hypothesis-driven.
-Instead of "develop faster and more practical coagulation methods," you could suggest: "Future research should investigate the effect of reducing stirring time to 30 minutes or adding a mineral catalyst to accelerate floc formation."
-For "Pathogen removal assessment," you could propose a specific experimental plan: "A key next step is to spike water samples with known concentrations of E. coli to quantitatively assess the log-reduction in bacterial count achieved by each coagulant."

4. Structural Polish for Maximum Impact:
The conclusion is strong, but it can be made more impactful. Consider restructuring it to:
-First, restate the main finding (Moringa is best).
-Second, briefly state the supporting evidence (It led in TDS, turbidity, hardness reduction).
-Third, state the broader implication (This provides a viable, low-cost DIY solution for rural communities).
-Finally, end with a powerful, forward-looking statement that echoes your introduction about the human right to water.

Congratulations on a superb research project!

Thank you for your thoughtful revisions. The paper has significantly improved in terms of consistency, coherence, and scientific presentation. I appreciate the effort you've put into refining the content. Below are a few remaining suggestions to further enhance the manuscript:

Abstract

Please include the common name of Moringa and provide its complete scientific name following the format used for the other three species.

Introduction

The sentence “In many regions of India, sewage systems are dysfunctional” appears abruptly. It would be more effective to first provide a general context about sewage challenges in developing countries, and then narrow the focus to India.

Page 3 – Last Paragraph

Kindly remove the repeated mention of TDS and turbidity reduction, as this information has already mentioned in same line.

Page 4

Avoid repeating the common names of species. Since they are already introduced at the beginning, subsequent references can use scientific names or common names (not both) for clarity and conciseness.

Introduction – Methods Section

As noted in the initial review, please remove the methodological details from the introduction. Specifically, the following passage should be relocated to the methods section:

Results and Findings

These sections are now well-structured and clearly presented. Excellent improvement!

Conclusion

I recommend removing the following lines from the conclusion and integrating them into the discussion section instead:

The concept of polyelectrolytes has not been introduced or discussed earlier, so its sudden appearance in the conclusion affects the logical flow. Including this explanation in the discussion will improve readability and strengthen the scientific narrative.

These refinements will enhance the overall clarity, structure, and impact of your paper. Let me know if you'd like help rephrasing any specific sections or integrating these suggestions.