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Sustainable Groundwater Purification: Leveraging Local Materials for Lead, Iron, and Cyanide Removal in Ghanaian Mining Communities

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study aims to evaluate the effectiveness of Moringa Oleifera seeds and banana peels as natural coagulants for the removal of lead, iron, and cyanide from groundwater in mining-affected communities in Ghana. Experimental laboratory analysis was used to analyze groundwater samples collected from five mining communities in the Atwima-Kwanwoma and Obuasi East

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districts of the Ashanti Region, Ghana, and treated with Moringa oleifera seeds and banana peels as natural coagulants. The concentrations of *E. coli*, cyanide, lead, and iron were measured before and after treatment. The study found a 100% removal efficiency for *E. coli*, cyanide, lead, and iron after treatment with Moringa oleifera seeds and banana peels. These results align with previous studies indicating the efficacy of these natural coagulants in water purification as the *Moringa oleifera* seeds and banana peels are effective, low-cost natural coagulants for removing contaminants from groundwater in mining communities.

Keywords: Natural coagulants; Moringa oleifera; banana peels; groundwater remediation; heavy metal removal; cyanide removal.

1. INTRODUCTION

Mining activities, particularly in regions rich with sulfur-bearing minerals, though a crucial source of economic development worldwide, often results in significant environmental degradation, one of the most critical being groundwater contamination. Acid mine drainage (AMD), which occurs when sulfide minerals are exposed to air and water, results in highly acidic water rich in iron. This, in turn, facilitates the dissolution of heavy metals such as lead (Pb), arsenic (As), cadmium (Cd), nickel (Ni), zinc (Zn), copper (Cu), mercury (Hg), and cyanide (CN), a byproduct of gold mining, into nearby groundwater or surface water sources, posing serious risks to environmental and public health and the disruption of ecosystems [1-3].

In Africa, particularly in Ghana, the impact of artisanal and large-scale mining operations has been profound, with numerous reports linking mining activities to the contamination of local water sources. This is especially concerning in rural areas where groundwater from wells and boreholes serves as the primary source of drinking water [4]. The contamination of these water sources with heavy metals and cyanides, substances often used in gold extraction processes, pose significant health risks to local populations [5]. Cyanide (CN), although naturally occurring in various biological entities, is predominantly introduced into the environment through such industrial activities, leading to severe ecological and health impacts [6]. Exposure to contaminated groundwater, particularly with heavy metals and cyanide (CN), poses significant health risks. These toxic substances can cause a wide range of acute and chronic health effects, including neurological damage, cancers, cardiovascular diseases, anaemia, organ failure, cirrhosis, kidney damage, and genetic disorders, often with severe or irreversible outcomes [7-9]. The problem is exacerbated by the inadequate enforcement of environmental regulations and the limited access to effective remediation technologies in many African countries.

Remediating heavy metals and cyanide (CN) contamination in groundwater from mining communities is crucial for public health and environmental safety. Traditional remediation methods, including chemical and physical treatments, are often too expensive or technically complex to implement in rural communities, necessitating the exploration of alternative, cost-effective solutions [10].

This study aims to address this gap by evaluating the effectiveness of locally available materials—specifically Moringa oleifera seeds and banana peels—as natural coagulants for the remediation of contaminated well water from five mining communities in the Ashanti Region of Ghana [11]. The study focuses on the removal of lead (Pb), iron (Fe), and cyanide (CN) from groundwater, offering a potential low-cost solution for improving water quality in mining-affected regions.

2. MATERIALS AND METHODS

2.1 Study Area Description

The study was carried out in five selected areas within the Amansie South District and Adansi North District of the Ashanti Region of Ghana, shown in Fig. 1. The Amansie South District, located at longitude 1°56'W and latitude 6°24'N, covers an area of approximately 1,364km^2, with the district capital, Manso Adubia, situated about 39.1km from Anwia-Nkwata and 65km from Kumasi, the capital city of the Ashanti Region. The Adansi North District, at longitude 1.0114°W and latitude 6.6074°N, spans an area of roughly 828km^2, with the district capital, Fomena, located about 28.2 kilometers from Anwia-Nkwata and 51km from Kumasi (Duker et al., 2004). The study focused on three mining communities in the Atwima-Kwanwoma District—Manso Wahaso (Town A), Manso Aponapong (Town B), and Manso Ankam (Town C) and two communities in the Obuasi East Municipality—Obuasi Dunkwaw (Town D) and Obuasi Suanso (Town E). Figs. 2–5 depict the mining areas in the selected communities.

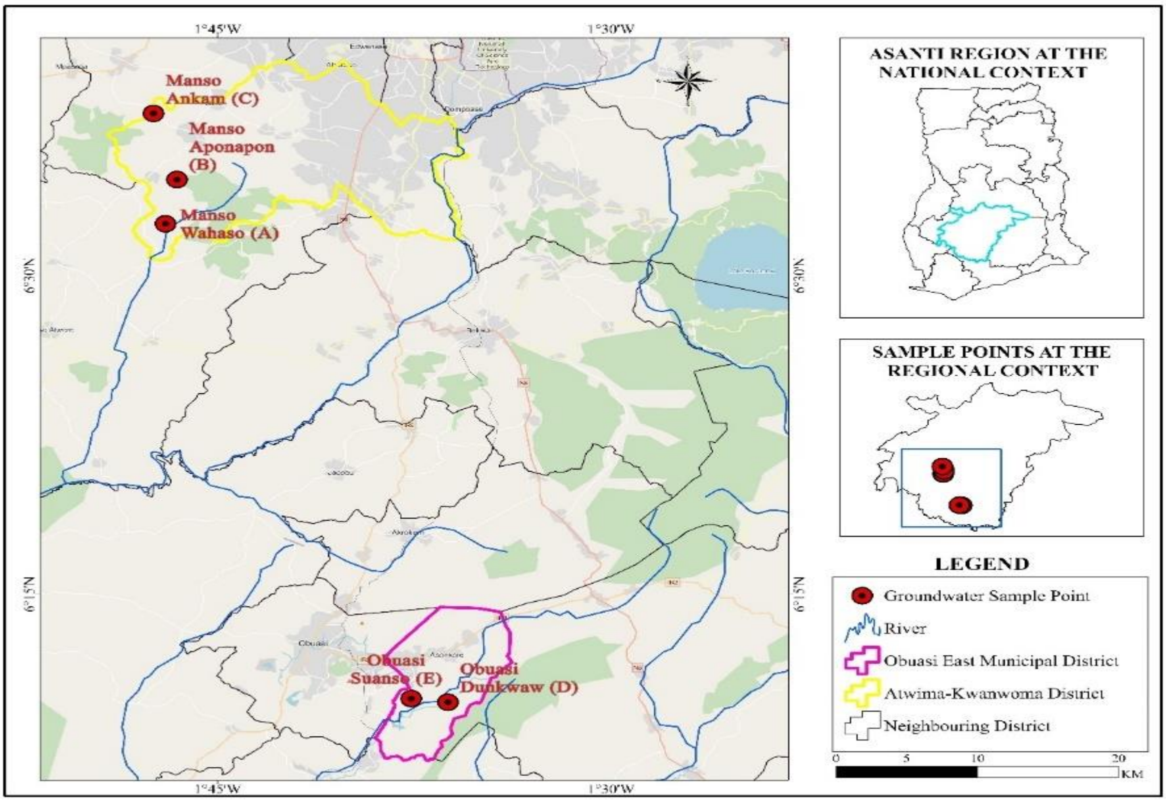

Fig. 1. Map of the Study Area (Ghana) indicating the Ashanti Region with the Atwima – Kwanwoma and Obuasi East Districts captured
Source: [12]

Fig. 2a. Map of Manso Wahaso indicating the Sampling Point A and the Small-Scale Illegal Mining Site
Source: [12]

Fig. 2b. Map of Manso Aponapon indicating the Sampling Point B and the Small-Scale Illegal Mining Site
Source: [12]

Fig. 3. Map of Manso Ankam indicating the Sampling Point C and the Small-Scale Illegal Mining Site
Source: [12]

Fig. 4. Map of Obuasi Dunkwaw indicating the Sampling Point D and the Small-Scale Illegal Mining Site
Source: [12]

Fig. 5. Map of Obuasi Suanso indicating the Sampling Point E and the Small-Scale Illegal Mining Site

Source: [12]

Illegal mining sites were identified and presented with respect to their distances from the sampling sites (Table 1).

2.2 Mapping and Sample Collection

Following the methodology outlined by Knödel et al. [13] monthly water samples were collected from three wells in each mining community over 12 months. The samples were taken upstream, downstream and close to the active mining and processing zones in the study area to evaluate the quality of the water resources and soil around the active mining and processing areas where effluents are directly discharged to the environment. Control samples were also taken monthly from wells at least 2 kilometres from the primary sampling wells. The samples upstream were mainly to serve as control points. A total of forty-eight (48) water samples were taken within the study area over one year; Two hundred and forty (240) water samples were collected into 250ml plastic bottles for physicochemical and heavy metal analysis. Another two hundred and forty (240) water samples were collected into 250ml plastic bottles placed into iced chests at a temperature of 4°C for microbial analysis. In effect, a total of four hundred and eighty (480) samples were collected. The water samples were acidified with nitric acid (HNO_3) to prevent leaching of any heavy metal present from the walls of the plastic bottles into the water samples, kept them in an oxidation state and set the pH of both the samples and standards equal. The sampling, storage and transportation of the water to the laboratory were done following standard protocols of APHA [14] to ensure consistency and data quality.

2.3 Laboratory Analysis and Pollution Indices

In drinking water quality assessments, priority is usually given to parameters that are known to be of concern to human health and potability when present in significant concentrations in the water source [15]. Therefore, heavy metals (i.e. Fe, Pb) and cyanide in the water samples were measured in the laboratory using the Atomic Absorption Spectrophotometer (AA-7000 SHIMADZU model) using the corresponding standards for lead and iron. The cyanide concentration of each sample was determined using the alkaline titration method [16]. 5% KI was used as the indicator and the endpoint of the titration was reached when the solution changed from a clear solution to a faint turbid yellowish solution. The samples were first digested using aqua regia, (a mixture of HCl and HNO_3 in ratio of 5:2) in a chemical fume hood. Water samples of 100 ml were measured into Erlenmeyer flasks, and 5 ml of HCl and 2 ml of HNO_3 were added successively in a fume hood. The samples were heated progressively and boiled on a hot plate for 2 hours, reducing the volume to about 20 ml. The distillates were allowed to cool down to ambient temperatures. The residue samples were filtered using an acid-resistant filter paper (Whatman filter paper) into a 100 ml volumetric flask. The Erlenmeyer flasks were rinsed several times with a small amount of deionized water into the volumetric flask. The solutions were then diluted to 100 ml with deionized water [17]. The resultant solutions were the test solutions analysed with an Atomic Absorption Spectrophotometer (AA-7000 SHIMADZU series model) using the spectro-photometric method.

The instrument was calibrated before analysing the samples with a blank and appropriate calibration standard.

The pH, electrical conductivity (EC), Temperature, Dissolved Oxygen (DO), and Total Dissolved Solids (TDS) were determined using the Eutech PC 700 Multi-Parameter checker and Salinity was equally determined using the same equipment. A buffer solution of pH 4 and pH 7 were used to calibrate the pH meter. The water samples were poured into a beaker and the electrode of the pH meter was rinsed with deionized water, and then inserted into the water samples, time was allowed for the reading to stabilize. The “MODE” key was pressed to toggle between Conductivity, DO, TDS and pH [to measure the pH of the samples [18]. The electrode of the pH meter was rinsed with distilled water before and after each reading.

2.4 Preparation and use of the Natural Coagulant

2.4.1 Moringa oleifera seed

After de-shelling, the *Moringa oleifera* seeds were baked at 105°C for 30 minutes. Using a pestle and mortar, the white kernels were ground into a fine powder. The powder was then sieved through a fine mesh 600 µm and collected in a sterile bottle and capped gently. 100 grams of the seed powder was used for the research work. For the coagulation experiment, the dried powder of the *Moringa oleifera* seed was stored under appropriate laboratory conditions [19]. For the coagulation experiment, different weights of the coagulant (defatted *Moringa oleifera* seed powder) were measured. 0.5 g, 1.0 g, 1.5 g, 2.0 g, 2.5 g, 3.0 g, 3.5 g, 4.0 g, 4.5 g and 5.0 g of seed powder were weighed and dissolved in 300 mL each of the ground water sample in a beaker, which was agitated for 15 minutes at room temperature, allowed to settle for 30 minutes, and filtered.

2.4.2 Banana peels

The coagulant preparation process was carried out according to Zurina et al [20] instructions. The banana peels were properly washed with distilled water to remove any contaminants before being sliced into little pieces ranging in size from 0.5 to 0.6 cm in length. The peels were dried for a week and then for 2 hours at 110℃ in the oven. The dried fruit peels were blended into a fine powder and sieved using a muslin cloth.

2.4.3 Flocculation or jar test operations using *Moringa oleifera*

The most popular experimental technique for coagulation-flocculation is the jar test (CF). This project employed a standard jar test apparatus to coagulate samples of the ground water using coagulants (*Moringa oleifera and banana peels*). It was conducted as a batch test using six beakers and six spindle steel paddles in succession. The sample was thoroughly mixed prior to the jar test. The samples then had their turbidity assessed. Coagulants were added to the beakers at various concentrations. The entire jar test method was carried out at various rotational speeds.

The beakers were stirred at various mixing times and speeds, including rapid mixing (250 rotations per minute, rpm) for 3 minutes and moderate mixing (25 rpm) for 15 minutes, once the necessary amount of powdered Moringa Oleifera seed had been added to the suspensions. The suspended (flocs) were allowed for 30 minutes to settle upon the stoppage of the agitation. Mixing duration and coagulant dosages were varied in order to explore the effects of each parameter on flocculation and to achieve the best possible results for each parameter.

The Stuart flocculator SW6 paddle Jar Test device was used to ensure uniform mixture of the ground water sample. There were six beakers labeled. Each beaker received about 300 ml of the ground water sample before being put into the Jar Test device. Each beaker received the appropriate stock solution concentration and was run for 3 minutes at an initial speed of 250 rpm. The speed was then lowered to 25 rpm and maintained for another 15 minutes. After the movement of the paddles seized, the resultant water was left to sit for 30 minutes [21,22]. After 30 minutes, the ground water sample was filtered into a beaker to be analyzed using the spectrophotometer (DR5000) with their powder pillows to check for the presence of heavy metals.

Coagulation is a chemical water treatment process that eliminates solids by changing the electrostatic charges of particles suspended in water [23]. In order to destabilize the particles, colloids, or oily materials in suspension, small, highly charged molecules are injected into the water.

Coagulation tests were carried out using the SW6 Stuart Rotor Jar Test Equipment and the jar floc test method (Fig. 6). Each of the six beakers received 500 mL of ground water. Then, a coagulant dosage was added for the coagulation test.

At a temperature of 24 ℃, the jar test was performed. Different ground water pH levels were explored in this experiment. To acquire the pH range that was evaluated, the pH of the ground water was changed to 1.0 M HCl and 1.0 M NaOH. To get the average results, the analyses was done twice. In this experiment, the coagulant dosage was set to a constant concentration of 10 mg/L.

The suspension was swirled for 3 minutes at 250 rpm, then 15 minutes at 25 rpm. This was done to ensure that the flocs particles are suspended uniformly. The mixture was allowed to settle for 1 hour before being filtered with filter paper. A portable turbid meter (HANNA instruments, HI88703) was used to conduct the turbidity test. For each sample, the decrease in turbidity and turbidity removal percentages were estimated using the formulas in Equations (1) and (2) respectively:

Turbidity Reduction = Initial Turbidity - Final Turbidity (1)

$$Turbidity\ reduction\ (\%) = \frac{initial\ turbidity - final\ turbidity}{initial\ turbidity} x100\% \quad (2)$$

The pH of the resultant water sample was then used to assess different coagulant concentrations ranging from 0.2 g to 1.2 g. The active chemicals from banana peel were extracted using NaCl concentrations of 1 M, 0.5 M, and 0.1 M, as well as NaOH concentrations of 0.1 M, 0.05 M, and 0.01 M, after these tests were completed using distilled water extracted coagulant. The solvent concentrations employed were similar to those used by Zurina et al [20] for rambutan seed extraction. This is to check if the same concentration was effective for the banana peel. Based on previous experiments, these suspensions of various concentrations were utilized as coagulants with the most effective pH of ground water and coagulant dosage.

Table 1. Illegal mining sites from sampling sites

Town	Name of Town	Distance (meters) to Illegal Mining Sites
A	Manso Wahaso	1241
B	Manso Aponapon	482
C	Manso Ankam	5722 (238 to a stream)
D	Obuasi Dunkwaw	15
E	Obuasi Suanso	1,374

Source: [12]

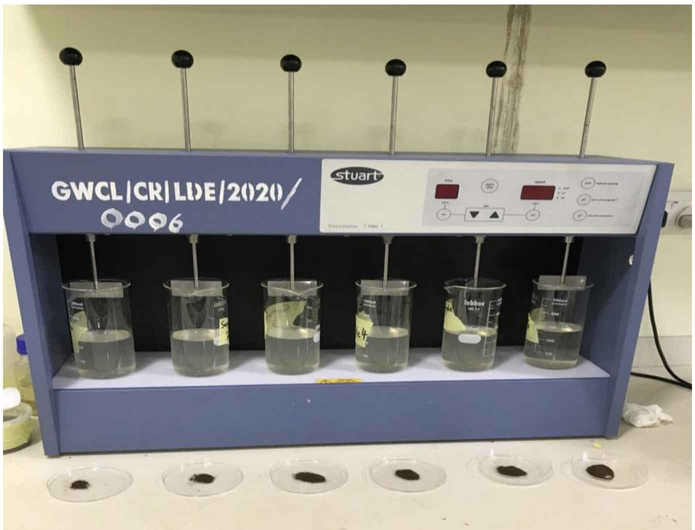

Fig. 6. Flocculation of Water Samples with Prepared Coagulants using SW6 Stuart Rotor Flocculator at the Ghana Water Company Limited (GWCL) Laboratory

3. RESULTS AND DISCUSSION

3.1 Physicochemical Characteristics of the Water Samples

The mean values of the key parameters of the water samples are presented in Table 2. The pH was 7.014, which is neutral. The Dissolved Oxygen, Electrical Conductivity, salinity and Total Dissolved Solids of the samples were 5.421 mg/L, 195.525 µS/cm, 13.38 ppm, and 18.938 ppm respectively. The mean cyanide, lead and iron concentrations were 1.024 mg/L, 0.937 mg/L and 1.115 mg/L respectively.

3.2 Water Purification Using *Moringa oleifera* Seed

Table 3 presents the results of treating sample groundwater using Moringa Oleifera Seed as a natural coagulant. The contaminants measured included *E. coli,* cyanide, lead, and iron.

Before treatment, the concentrations of *E. coli* were measured at 310.00 CFU/100 ml. However, after treatment with *Moringa oleifera* Seed, the *E. coli* concentration was reduced to 0.00 CFU/100 ml. This indicates a 100% removal of *E. coli,* effectively eliminating the presence of this harmful bacteria in the treated water [24].

Similarly, Cyanide, Lead, and Iron concentrations were also significantly reduced after treatment with *Moringa oleifera* Seed. Cyanide concentration decreased from 3.250 mg/L to 0.00 mg/L, resulting in a 100% removal. Lead concentration decreased from 2.061 mg/L to 0.00 mg/L, also achieving a 100% removal. Iron concentration decreased from 2.489 mg/L to 0.00 mg/L, with a removal percentage of 100%.

These results align with previous research studies that have investigated the use of Moringa Oleifera Seed as a natural coagulant in water treatment [25,26].

The findings of this study provide evidence of the effectiveness of *Moringa oleifera* Seed as a natural coagulant in removing contaminants from groundwater. This is in line with the findings of Camachoet al [27] on Moringa as natural coagulant. The results are consistent with previous research that has reported high removal rates for *E. coli,* Cyanide, Lead, and Iron using Moringa Oleifera Seed as a coagulant [28,25,26].

3.3 Water Purification Using Banana Peels as a Natural Coagulant

Table 4 presents the results of treating sample groundwater using Banana peels as a natural coagulant. The contaminants measured include *E. coli*, Cyanide, Lead, and Iron. Specific groundwater samples were collected and tested before treatment for their various concentrations (i.e. *E. Coli*, Cyanide, Lead & Iron), which were higher than the mean values in Table 2. Subsequently, the treated water samples using the various coagulants and the removal efficiency of 100% were recorded. Interestingly, the higher values of contaminant concentrations in Table 4 as compared to those in Table 2 were deliberate only to prove a point in the removal efficiency of the natural coagulant.

Before treatment, the concentrations of *E. coli* were measured at 310.00 CFU/100 ml. After treatment with Banana peels as a natural coagulant, the *E. coli* concentration was reduced to 0.00 CFU/100 ml, indicating a 100% removal. These findings are consistent with the results reported by Bhattacharya and Sen [29] who investigated the use of Banana peels as a coagulant for water treatment.

Table 2. Statistical summary of the physicochemical parameters for all the Five Towns

Statistics	pH	DO	EC	Sal	TDS	CN	Pb	Fe
Mean	7.014	5.421	195.525	13.282	18.938	1.024	0.937	1.115
Std	0.658	0.694	85.383	0.679	8.517	0.790	0.484	0.622
Median	7.025	5.475	182.330	13.243	17.672	0.765	0.702	1.004
%CV	9.383	12.802	43.668	5.116	44.975	77.167	51.594	55.766
Max	8.320	7.290	501.790	15.940	47.635	2.410	1.806	2.543
Min	5.645	4.075	101.100	11.665	10.305	0.128	0.398	0.232
SE	0.040	0.042	5.197	0.041	0.518	0.048	0.029	0.038
Kurtosis	-0.697	-0.507	6.994	1.685	5.049	-1.008	-0.998	0.188
Skewness	0.101	0.219	1.642	0.925	2.167	0.726	0.834	1.013

Table 3. Purification using *Moringa oleifera* Seed as a natural coagulant

Contaminants	Before Treatment	After Treatment	Percentage removal	WHO, 2017 Guideline
E. coli (CFU/100ml)	310.00	0.00	100	0.00
Cyanide (mg/L)	3.250	0.00	100	0.07
Lead (mg/L)	2.061	0.00	100	0.01
Iron (mg/L)	2.489	0.00	100	0.30

Table 4. Remediation using banana peels as a natural coagulant

Contaminants	Before Treatment	After Treatment	Percentage removal	WHO, 2017 Guideline
E. coli (CFU/100 ml)	310.00	0.00	100	0.00
Cyanide (mg/L)	3.250	0.00	100	0.07
Lead (mg/L)	2.061	0.00	100	0.01
Iron (mg/L)	2.489	0.00	100	0.30

Similarly, the concentrations of Cyanide, Lead, and Iron were significantly reduced after treatment with Banana peels. Recent studies on Banana peel seem to support our findings on the removal efficiency of contaminants in water as a coagulant. Al Haider et al. [30] demonstrated the use of Banana peel-activated carbon for contaminant removal; [31] used Banana peel as a biosorbent for contaminant removal and Azamzam et al [32] adopted Banana peel-coagulant in turbid and river water treatment applications. Cyanide concentration decreased from 3.250 mg/L to 0.00 mg/L, resulting in a 100% removal. Lead concentration decreased from 2.061 mg/L to 0.00 mg/L, also achieving a 100% removal. Iron concentration decreased from 2.489 mg/L to 0.00 mg/L, with a removal efficiency of 100%. These results align with the findings of the studies conducted by Maurya and Daverey [33], Azamzam et al [34] which investigated the efficacy of Banana peels as a natural coagulant in water treatments.

The findings of this study provide evidence of the effectiveness of Banana peels as a natural coagulant in removing contaminants from the well water. The results agree with the research conducted by Bhattacharya and Sen [29] and Azamzam et al [34] indicating the potential of Banana peels as an alternative coagulant in water treatment processes.

4. CONCLUSION

This study demonstrated the effectiveness of *Moringa oleifera* seeds and banana peels as natural coagulants for the remediation of contaminated groundwater in mining-affected communities in Ghana. The research specifically targeted the removal of critical pollutants such as lead, iron, and cyanide, which are prevalent due to extensive mining activities in the region. The treatment with *Moringa oleifera* seeds resulted in a 100% removal efficiency for *E. coli*, cyanide, lead, and iron from the groundwater samples. This suggests that Moringa seeds are highly effective as a natural coagulant in water purification, aligning with prior research that underscores its potential in removing organic and inorganic contaminants from water. Similarly, banana peels achieved a 100% removal efficiency for the tested contaminants. The success of banana peels as a coagulant confirms the viability of using agricultural waste products in environmental remediation, offering an eco-friendly and cost-effective alternative to conventional chemical treatments.

The use of locally available, low-cost materials like *Moringa oleifera* seeds and banana peels present a sustainable solution for addressing water contamination in rural mining communities. This approach not only mitigates environmental pollution but also promotes the use of natural resources in a manner that is both accessible and affordable for local populations. The findings advocate for the integration of these natural coagulants into broader water management and remediation strategies, particularly in regions where industrial contamination poses significant health risks.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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