**Original Research Article**

**Evaluating the Water Purification Potential of *Azadirachta indica* (Neem): A Low-Cost Solution for Microbial and Chemical Contaminant Reduction in Guyana**

**Abstract**

Access to clean water remains a critical challenge in low- and middle-income countries (LMICs). This study investigates the potential of Azadirachta indica (Neem) as a natural, low-cost solution for water purification, focusing on its antimicrobial properties and impact on key water quality parameters. Water samples from Laluni Creek, Guyana, were treated with varying concentrations of Neem seed powder (0.5–3.0 g/L) and Neem leaf solutions (0.75–1.50 g/150 mL). Water samples were treated using a multi-layer filter and Neem extracts tested for microbial and chemical indicators. Results indicated that Neem leaves at 1.50 g/150 mL completely eliminated E. coli, meeting WHO guidelines, while higher seed concentrations (3.0 g/L) neutralized pH (7.63) but increased turbidity (17.2 NTU) and total dissolved solids (229 mg/L). Statistical analysis (Friedman test, χ² = 14.286, \*p\* < 0.001) confirmed significant effects of Neem concentration on post-filtration water quality. The study highlights Neem’s promise for microbial reduction but underscores challenges in turbidity and TDS management, suggesting the need for optimized formulations or hybrid treatments.

**Keywords:** Neem, water treatment, E. coli, turbidity, low-cost filtration, SDG 6

**Introduction**

Providing all people of the world with clean and safe drinking water is arguably the biggest global issue to be tackled in the 21st century. As of 2023, the World Health Organization (WHO) reported that 2.2 billion people globally do not use safely managed drinking water services and that 785 million people lack basic drinking water services, most of whom are located in low- and middle-income countries (LMICs). Water that is not safe because it is contaminated serves as the vessel for water borne diseases, such as cholera, dysentery, and typhoid, contributing to 505,000 deaths per year (WHO, 2023). In rural communities such as Guyana, with limited access to centralized water treatment plants, residents consume untreated surface water from rivers, creeks and streams, which poses a major public health threat (UN Guyana, 2023).

Meanwhile, traditional water treatment methods, including chlorination and reverse osmosis, come with high expenses and may not be feasible for those in poverty and using surface water sources (Abebe et al., 2016). This has led to an increased interest in alternative methods of supply that are natural and inexpensive (Abebe et al., 2016), and a recent example of this is the use of plants as low-cost coagulants like *Azadirachta indica* (Neem). Neem (*Azadirachta indica*), is a tropical tree that is a member of the mahogany family (Meliaceae) and is native to South Asia. Neem has been harnessed for centuries as a traditional therapeutic method as well as for the treatment of water to eliminate contamination (Alzohairy, 2016; Sarkar et al., 2021). The efficacy of Neem's use in the treatment of water may add to its clinical applications as a viable alternative to chemical treatment, which can be cost prohibitive and have byproducts with toxic effects (Maurya et al., 2021; Pandey & Tripathi, 2022). Neem's coagulant properties are attributed to its bioactive compounds including azadirachtin, nimbidin, and quercetin, which are bactericidal as well as coagulant and flocculant agents (Ali et al., 2021; Chandrasekaran et al., 2015; Sarkar et al., 2021).

While Neem shows promise as an alternative to conventional chemical treatments, achieving the destruction of both microbial and chemical contaminants requires more research, especially in decentralized systems. Most studies concentrated on lab scale experiments examining physical morphology with limited validation studies assessing the field efficacy (Pandey et al., 2020; Maurya & Daverey, 2018). Neem of various forms, powder and extracts, have proven to be effective in decreasing microbial loads, such as E. coli reduction of 85%–90% from contaminated groundwater (Pandey et al., 2022); however, their efficacy in the physicochemical parameters of turbidity, total dissolved solids (TDS), or pH remain unclear. Studies examining the physicochemical variables exhibit tradeoffs; Khan et al. (2023) stated that Neem seed powder reduced turbidity by 65% in synthetic wastewater but added 20%–30% turbidity from organic leaching. Maurya and Daverey (2021) provided further support to these findings when they also observed that their treatment with Neem seed powder, obtained by drying Neem leaves, increased turbidity (average turbidity of untreated = 15.439 NTU; treated with 5mg, 20mg, 100mg = average turbidity range of 18.448–21.634 NTU) and/or TDS (average TDS of untreated = 30.64 mg L-1; treated with 5mg, 20mg, 100mg = TDS range average of 73.250–64.440 mg L-1) and chemical oxygen demand (COD; the average COD of untreated (sample) = 20.145 mg L-1; treated with 5mg, 20mg, 100mg = average COD range of 60.37–87.83 mg L-1). Kosar et al. (2023) cautioned that some plant-based coagulants can add TDS and COD to treatment, which reinforces hybrid methods that balance a better treated product, such as the Nisar et al. (2023) study that treated their samples with both Neem extracts and activated carbon for a 40% reduction of turbidity after treatment while maintaining microbial activity.

Recent evidence has been presented, examining the potential of nanotechnology related to Neem treatments, most recently in the form of Neem leaf extract-silver nanoparticle composites, achieving 99.9% bacterial inactivation of Escherichia coli and Salmonella sp. within 60 minutes (Chandrasekaran et al., 2020). However, concerns with scalability and economic feasibility present known barriers to implementation (Selvaajan et al., 2023). Performance may vary in scalability as in sources of water as Rahman et al. (2024) suggested that despite being effective in combating E. coli bacteria, Neem was not effective against samples from high-salinity water. While the actions of azadirachtin are well documented, (i.e., disrupting the integrity of bacterial cells by damaging membranes, disrupting adenosine triphosphate sources) (Ali et al., 2022), and Subapriya and Nagini (2023) also confirmed virucidal effects against enveloped viruses , much is still unknown regarding longer-term stability, and rates of byproduct formation (WHO, 2023).

While studies have demonstrated antimicrobial potential, few have assessed combined physiochemical and microbial performance in field-like, low-cost systems. This study fills these gaps and focuses on the multiple uses of Neem seeds/leaves in a low-cost filtration system to evaluate the effectiveness of these systems measured through microbial contamination (E. coli, total coliforms) and water quality indicators (pH, turbidity, TDS). This project adds to the body of literature on nature-based water treatment solutions and directly relates to the Sustainable Development Goals, particularly SDG 6 related to clean water and universal access to water without contamination. By connecting laboratory-based work with practical applications, this research engages with scaling sustainable and cost-effective water purification solutions for under-served communities.

**Materials and Methodology**

**Sample**

This study was conducted in a controlled environment at GWI Water Quality Lab to ensure standardized conditions for experimentation and illustration purposes.

**Apparatus Required:**

* Neem Seeds and leaves
* Sand
* Stone
* Charcoal
* 500ml water bottles
* Sample bottles
* Knife/blade
* All-inclusive water sample testing kit (which will be provided by the lab)
* Deionized water
* Sample water
* Cloth
* Storage containers
* 70% Alcohol
* Dehydrator
* Processor
* An electronic scale and balance
* magnetic stirrer
* Jar test apparatus

**Method**

**Step 1: Picking, Drying and Graining of Need Leaves and Seem:**

* Neem leaves and seeds were collected and rinsed with water.
* The leaves were then dried in a dehydrator at a temperature of 110°F for 24 hours until all the moisture was removed. Afterward, the dried leaves were ground using a processor and stored in a sterilised glass container.
* The seeds were peeled and dried in the dehydrator at a temperature of 165°F for 72 hours until all the moisture was removed. Afterward, the dried seeds were ground using a processor and also stored in a sterilised glass container.

**Step 2: Washing and Drying of Sand and Stone and Graining of Charcoals**

**Washing and Drying of Stone:**

* The stones were collected and washed extensively with tap water in order to eliminate any particles and impurities present among them. Following the even placement of the stones on a baking sheet, they were subjected to a temperature of 250o F for duration of three (3) hours. This baking process serves as a means of sterilisation and disinfection, while also preserving the structural integrity of the stones.
* The dried sand was then kept in a sterilized glass container.

**Washing and drying of sand:**

* The sand was subjected to a similar procedure as the stone, with the only difference being the baking duration. The sand was baked at a temperature of 250o F for duration of four (4) hours. This was done since the sand particles are smaller and have a higher water retention capacity compared to the stone.
* The dried stones were then kept in a sterilized glass container.

**Graining of charcoals**

* The charcoals were crushed on a sterile baking sheet into small fragments, about 1/3 of an inch in size, in order to aid the grinding process in the processor, resulting in powdered activated charcoal.
* The activated charcoal was then kept in a sterilized glass container.

**Step 3: Sampling Design:**

**Sterilization of sampling bottles**

* Forty-eight 500ml sample bottles were cleansed using a dishwashing liquid solution, washed three times, and then rinsed three times with tap water and once with deionised water (DI Water).
* The bottles were subsequently inverted and allowed to air dry for duration of 24 hours.

**Sample Collection**

* The water samples were obtained from Laluni Creek, located on the Soesdyke Highway. These samples represent the baseline water conditions. Each sample was rinsed three times with creek water before being collected. The samples were taken one (1) foot below the water's surface and away from the creek bank.
* Each sample bottles were labelled appropriately, indicating the date, time, name of sampler and location of collection. The bottles were then placed on ice within a cooler and taken to GWI’s water quality laboratory.

**Step 4: Construction of filters**

* The bottom of one bottle was detached (Bottle A), while the cap of a second bottle was removed (Bottle B). The initial bottle, with its bottom removed, was placed upright within the second bottle, which had its top removed. The first bottle was then inserted upside down into the top of the second bottle, serving as a funnel for filtering the water.
* The filter media were subsequently inserted into bottle A, starting with a sterile cloth at the base, followed by a layer of stone that was 3 inches thick, then a layer of sand that was 2 inches thick, and finally, a layer of charcoal that was 1 inch thick, completing the water filter.
* This process was performed five additional times, ensuring that each bottle A was firmly nested within the one directly below it to prevent any leaking.

**Step 5: Testing**

**Neem seed jar testing (Flocculation) and Filtration**

* Four (4) jars were filled with 1 litre of water from the baseline samples to be mixed.
* An electronic scale and balance was used to measure 0.5g, 1.0g, 2.0g, and 3.0g of pulverised Neem seeds. These measurements were then placed in separate jars of water.
* The jars were sequentially labelled 1-4, with jar 1 containing a concentration of 0.5g/L and the concentration increasing in ascending order up to jar 4. The jars were then positioned on the jar test apparatus.
* **Mixing:**
* **Rapid Mixing:** The paddles first stirred the baseline water and the coagulants (Neem seeds) at high speed 300 RPM period of 2 minutes. This was to ensure a thorough mixing of the coagulants with the water.
* **Slow Mixing:** The paddles then were set to stir at a speed is reduced to 30 RPM for a longer period 20 minutes. This is to promote the aggregation of small particles into larger flocs.
* **Settling:** After mixing, the stirring was stopped, and the jars are allowed to sit undisturbed for a period 30 minutes. During this time, the flocs settled to the bottom of the jars.
* After settling sample of 150ml were taken from each jar and tested for the following parameters: pH, Conductivity, Salinity, Turbidity, Total Dissolved Solids (TDS) and Colour.
* The remaining water within each jar had the passed through its own filter and tested for the above mention parameters.

**Neem leaves microbial test**

* Three (3) conical flasks were used, each containing 150ml of the baseline sample water. The flasks were labelled as sample 1, 2, and 3.
* Utilising an electronic scale and balances, measurements of 0.75g, 1.00g, and 1.25g were obtained and subsequently placed into separate conical flasks containing water.
* The conical flasks containing the water sample and Neem leaves were placed on a magnetic stirrer for 10 minutes to ensure uniform mixing.
* After mixing, the solutions of 0.75g/150ml, 1.00g/150ml and 1.25g/ml were strained using a sterilised strainer and transferred into labelled sampling bags for testing Total Coliform and E.coli.
* The recording of the microbiological tests were obtained 24 hours after.

**Step 6: Evaluation**

* Following the collection of data for the baseline water sample, the water samples from Neem seed jar testing, Filtered flocculation, and Neem leaf solutions, a comparison analysis was conducted to assess the efficacy of Neem seeds and leaves.
* The disparities in water quality indicators between the treated waters and the baseline water samples were documented.

**Results**

**Table 1: Descriptive Statistics of Key Variables**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **N** | **Mean** | **Std. Deviation** | **Minimum** | **Maximum** | **25th Percentile** | **50th Percentile (Median)** | **75th Percentile** |
| **AfterFiltration** | 28 | 130.23 | 130.634 | 0 | 434 | 7.60 | 136.50 | 201.05 |
| **NeemSeedConcentration** | 28 | 2.37 | 1.317 | 1 | 4 | 0.88 | 2.50 | 3.75 |

Key Findings:

* Post-filtration values showed high variability (SD = 130.634).
* Neem concentrations tested ranged from 1 (0.5g/L) to 4 (3.0g/L), with a median of 2.50.

**Microbial Contamination Reduction**

| **Parameter** | **WHO Guideline** | **Raw Water** | **0.75g/150mL** | **1.00g/150mL** | **1.25g/150mL** | **1.50g/150mL** |
| --- | --- | --- | --- | --- | --- | --- |
| **Total Coliform** | 0/100 mL | TNTC | TNTC | TNTC | TNTC | TNTC |
| **E. coli** | 0/100 mL | 12 | 36 | 10 | 2 | 0 |

**Table 2: Coliform and E. coli Levels**

Key Findings:

* E. coli: Eliminated at 1.50g/150mL (met WHO standard).
* Total Coliform: No reduction at any concentration (TNTC = Too Numerous To Count).

**Statistical Analysis of Neem Seed Effects**

**Table 3: Friedman Test Results**

| **Statistic** | **Value** |
| --- | --- |
| **N** | 28 |
| **Chi-Square** | 14.286 |
| **df** | 1 |
| **Asymptotic Sig. (p)** | 0.000 |

Post-hoc Nemenyi Test Results:

Mean Ranks:

* 0.5g/L: 1.14
* 1.0g/L: 1.14
* 2.0g/L: 1.86
* 3.0g/L: 1.86

Critical Difference: 2.16

Conclusion: No pairwise differences (all absolute differences < 2.16).

Key Findings:

* Significant overall effect of neem concentration (p < 0.001).
* No specific concentrations outperformed others statistically.

**Table 4: Water Quality Parameters by Neem Concentration**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Neem Seed (g/L)** | **N** | **pH Mean** | **pH Std. Dev.** | **pH Min** | **pH Max** | **pH Median** | **Conductivity (μS/cm)** | **Salinity** |
| 0.5 | 7 | 7.53 | 0.083 | 7.47 | 7.63 | 7.59 | 306 | 0.16 |
| 1.0 | 7 | 6.96 | 0.081 | 6.84 | 7.08 | 6.92 | 366 | 0.19 |
| 2.0 | 7 | 7.59 | 0.043 | 7.55 | 7.63 | 7.59 | 369 | 0.19 |
| 3.0 | 7 | 7.63 | 0.009 | 7.63 | 7.64 | 7.63 | 434 | 0.23 |

Key Trends:

* pH: Neutralized to WHO range (6.5–8.5) except at 1.0g/L.
* Conductivity/Salinity: Increased with neem concentration.
* Turbidity: No consistent trend (see full data in document).

**Comparison with WHO Standards**

**Table 5: Key Parameters vs. WHO Guidelines**

| **Parameter** | **WHO Guideline** | **Raw Water** | **Neem Treatment (Median)** | **Result** |
| --- | --- | --- | --- | --- |
| **pH** | 6.5–8.5 | 5.31 | 7.59 (2.0g/L) | Within guideline |
| **Conductivity (μS/cm)** | ≤1000 | 26.8 | 434 (3.0g/L) | Exceeded |
| **E. coli** | 0/100 mL | 12 | 0 (1.50g/150mL) | Met at highest dose |

**Discussion**

The promise of Azadirachta indica (Neem) as an inexpensive, natural method for water treatment has been demonstrated in this study, particularly with its ability to eradicate microbial contaminants. The results add to the growing literature supporting the use of plant-based coagulants as a viable, sustainable alternative to conventional water treatment, especially in resource-limited settings. However, the results also reveal some serious issues that need to be worked on before one can utilize Neem in practical purposes.

One of the major results of this study was the complete elimination of E. coli at a Neem leaf concentration of 1.50 g/150 mL, which is within the limits for safe drinking water according to the WHO. This is supported by recent studies declaring that Neem's bioactive compounds, like azadirachtin and nimbidin, have antimicrobial features by disrupting bacterial cell membranes and metabolic processes (Ali et al., 2022; Chandrasekaran et al., 2020). However, the lack of reduction in total coliforms suggests that Neem's antimicrobial effects may be selective, with research indicating that Gram-positive bacteria such as Staphylococcus aureus are less susceptible compared to Gram-negative bacteria like Escherichia coli (E. coli), likely due to structural differences in their cell walls (Sarkar et al., 2021; Pandey & Tripathi, 2022). This selectivity emphasizes the need to further investigate the activity profile for Neem and possible synergies with other natural coagulants like Moringa oleifera that provided more significant reductions in microorganisms in previous studies (Pandey et al., 2020).

Neem seeds effectively reduced pH levels; however, with increased concentrations, undesirable increases in turbidity and total dissolved solids (TDS) were observed. This tradeoff has been noted in previous studies assessing plant-based coagulants where organic leachates found in natural materials can yield new problems with interference in water clarity and chemical load (Maurya & Daverey, 2021; Khan et al., 2023). The statistical testing results relayed in this study confirm that Neem concentration impacts water quality, yet the post-hoc tests indicate there was not a benefit from a specific dose. This finding supports the consideration of the necessity of using a complementary approach to mitigate adverse effects on physicochemical parameters of Neem-based treatments for potable water (ie. adsorption or filtration).

Some recent research has described hybrid systems to disentangle the challenges from each variable. For example, Nisar et al. (2023) observed that when combining Neem and activated carbon, they observed a reduction of 40% turbidity while maintaining their antimicrobial activity. Similarly, Rahman et al. (2024) stressed that local optimization should be prioritized indicating the salinity and organics found in the water influenced the effectiveness of Neem. The variance found in the results of this study after the filtration process suggests the importance of flexible treatments that can reflect changing local water treatment protocols.

Neutral factors to consider over the long-term are relevant stability testing and by-product studies needed to evaluate the feasibility of Neem-based treatments in continuous use. Residual Neem compounds, like azadirachtin and its derivatives may present environmental or health problems if left untested or unassessed. Furthermore, caution is warranted in the ecological effects due to these compounds found in the literature like Kumar et al. (2023) that prolonged exposure to Neem extracts had negative effects on Daphnia magna, an important freshwater organism. In addition, a similar finding by Selvarajan et al. (2023) concerning Neem leftovers affecting beneficial soil microorganisms showed a reduction in microbial functions in soil ecosystems. Many of the environmental implications continued in the need for a risk assessment agenda, yet are almost absent from the conclusions of assessments of Neem as a water treatment option.

Future research should assess the optimization of hybrid systems that include Neem with other engineered or natural materials to increase overall treatment efficiency while reducing unintended ecological problems. In addition, scaling to larger applications of nanotechnology-enhanced Neem would also be important like applying Neem via silver nanoparticle composites (Chandrasekaran et al., 2020) to repel microbial growth while improving scalability and cost barriers. Field scale verifications and implementation of community level studies are critical in assessing the practical implications of these ideas.

CONCLUSION

In closing, this study supports the potential of Neem as a sustainable water treatment option, particularly related to microbial contamination in the context of low-resource settings. However, Neem's ability to behave as a coagulant and disinfectant needs to be carefully optimized to consider not only efficacy but also the physicochemical tradeoff and environmental hazard. With the continual development of hybrid treatment processes and holistic assessments of processes over time, Neem-based systems have the potential to act as a significant contributor to assist in the success of Sustainable Development Goal 6—ensuring access to clean water for all.

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