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An Automated Non-Sewage Wastewater Treatment Facility using *Moringa oleifera* Seeds

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Abstract

Objective: This study aimed to address the problem of non-sewage wastewater treatment as a potential source of potable water. While earlier research explored chemical-based and manual filtration systems, limited attention has been given to combining automation with natural coagulants. The study designed and tested an automated non-sewage wastewater treatment system using *Moringa oleifera* seeds to improve the quality of rainwater to drinkable levels. **Methods:** A developmental-experimental research design was adopted, involving the construction and testing of an Arduino-based automated treatment unit that controlled coagulation, sedimentation, and filtration. *Moringa oleifera* seed extract served as the natural coagulant, while sensors ensured precision and consistency in dosing and mixing. Rainwater samples were analyzed before and after treatment for key physicochemical parameters—pH, turbidity, total dissolved solids (TDS), and conductivity—following the Philippine National Standards for Drinking Water (PNSDW), World Health Organization (WHO), and Environmental Protection Agency (EPA) guidelines. Verification was conducted at the Partido State University Water Testing Facility. **Findings:** Results showed that the treated water met all regulatory standards, with 0 FNU turbidity, pH 6.53, TDS 21.53 mg/L, and conductivity 32.47 μS/cm, indicating total removal of suspended particles and low ionic residues. Nutrient concentrations, including phosphate (1.21 mg/L) and nitrite (0.1 mg/L), were significantly below EPA limits, demonstrating enhanced nutrient removal compared with manual Moringa treatments. The automated system ensured stable pH levels and eliminated the variability commonly observed in manual dosing, yielding consistent and reproducible outcomes. **Novelty:** This study presents an eco-friendly, low-cost, and automated water treatment innovation that combines *Moringa oleifera* coagulants with automation technology. It achieved complete turbidity removal, improved nutrient reduction, and stable water chemistry, offering a sustainable and reproducible approach to community-level potable water production.

Keywords: Non-sewage wastewater; Treatment Facility; *Moringa oleifera* Seeds; Arduino-based; Potable Water

1 Introduction

The increasing interest in water scarcity and pollution the world over highlights the importance of the need to create viable and available treatment systems. In most regions of the globe, especially those in the developing world, the most non-sewage wastewater, which includes storm runoffs and agricultural effluents is left untreated even though it can be used. This issue is enhanced by the constraints of traditional treatment systems relying on chemical coagulants as well as mechanical filtration systems. Although these are effective in minimizing turbidity and contaminant, they are costly, consumes energy and unsustainable to the environment and usually results in chemical residues which are harmful to the ecosystems. These endemic problems help understand the situation of the problem and the necessity of new low-cost and environmentally friendly solutions.

Natural or plant-based coagulants have attracted increasing attention as sustainable alternatives to synthetic agents. Among these, *Moringa oleifera* seeds exhibit strong coagulation and adsorption properties. Previous studies have demonstrated that *Moringa oleifera* extracts effectively remove turbidity, suspended solids, and antibiotic-resistant bacteria, with performance comparable to alum-based treatments [1], [2]. Low-cost clarification systems using *Moringa oleifera* have also achieved significant reductions in turbidity and color [3], [4]. However, most existing systems operate manually, lack real-time monitoring and precise dosage control, and are primarily limited to laboratory-scale or batch processes [5]. Consequently, their scalability and operational consistency remain constrained. To date, no study has reported the integration of *Moringa*-based biocoagulation with sensor-controlled, Arduino-based automation for non-sewage wastewater treatment. This gap presents both a technical innovation opportunity and a pathway toward environmentally sustainable water treatment solutions.

This paper put forward the design and development of an Arduino-based automated non-sewage water treatment system where the natural coagulant is the Moringa oleifera seeds. The project is expected to (1) develop the automated system; (2) compare the physicochemical and bacteriological characteristics of the wastewater before and after treatment; and (3) determine the performance of the system regarding the rate of suction, filtration rate, dosing volume, agitator speed, and discharge flow rate. The originality of the given research is the integration of the green biocoagulation with smart automation, which will increase the accuracy, efficiency, and scalability. This methodology does not only outperform the manual systems of the past literature; it also presents a flexible and sustainable treatment framework which is applicable to communities with limited resources. It is important to note that recent optimization works attest to the flexibility and good coagulant activity of Moringa on different wastewater [6].

On a larger scale, the paper highlights the potential of synergy between natural resources that are indigenous and technological innovation. Combining the environmental advantages of Moringa treatment with the accuracy of Arduino-based automation, it transforms the concept of water purification into the scientific and socio-environmental innovation. Finally, the project will help in achieving the United Nations Sustainable Development Goal (SDG) 6 on clean water and sanitation, which will provide a progressive approach in managing water sustainably in developing environments.

2 Methodology

This section presents the methodological frameworks employed in this study which emphasizes the use of developmental-experimental approach, adopted a systematic developmental procedure, and evaluated the automated non-sewage wastewater treatment facility utilizing *Moringa oleifera* seeds as a natural coagulant

2.1 Research Design

The research design that was used in this study was a developmental-experimental research design to design, fabricate and test an automated non-sewage wastewater treatment facility which used *Moringa oleifera* seeds as a natural coagulant. The developmental model was concerned with the invention and improvement of the gadget and the experimental model investigated how well the device worked in enhancing the physico-chemical as well as bacteriological characteristics of non-sewage wastewater, which is rainwater. The objective of the study was to find out the effectiveness of the device to improve the turbidity, pH, total suspended solids (TSS) and dissolved oxygen (DO) and the number of total coliform in the water. By doing so, the research used the findings to confirm or dismiss its hypothesis by finding that there were significant differences in untreated and treated water samples, based on the conceptual framework of study.

A developmental–experimental research design was adopted in this study. The developmental component focused on the design, construction, programming, and optimization of an automated non-sewage wastewater treatment facility incorporating *Moringa oleifera* seed extract as a biocoagulant. The experimental component evaluated the effectiveness of the developed system in improving the physicochemical and microbiological quality of non-sewage wastewater samples, primarily rainwater.

The performance of the system was quantitatively assessed by comparing untreated and treated water samples in terms of turbidity, pH, total suspended solids (TSS), dissolved oxygen (DO), and total coliform count. These parameters served as the study's primary endpoints for determining treatment efficiency and verifying the research hypothesis.

2.2 Sampling Procedure

Non-sewage wastewater samples, specifically rainwater, were collected using sterilized polyethylene containers from designated collection points to avoid external contamination. Samples were transported immediately to the treatment facility and processed within the same day to preserve their original characteristics. Untreated samples were retained as controls for comparative analysis.

2.3 Treatment Procedure

Treatment was carried out using the developed Arduino-based automated system. *Moringa oleifera* seed extract was prepared following standard seed processing protocols and introduced into the wastewater through an automated dosing mechanism. The system regulated dosing volume, mixing speed, suction rate, sedimentation time, and filtration rate using pre-programmed control logic.

The treatment process involved sequential stages of coagulation, flocculation, sedimentation, and filtration. Automation ensured consistent operational conditions across all trials, minimizing human error and variability commonly associated with manual treatment systems.

2.4 Developmental Procedures

The automated treatment facility was developed in six systematic steps namely planning, designing, programming, fabrication, testing and modification. Scientific rigor was followed in every step to guarantee the accuracy of the final prototype, reliability, and functionality respectively.

2.4.1. Planning Phase

At the planning phase, the researchers made a preliminary review of the related literature and assembled information on the availability of materials, design feasibility, and cost estimates. The planning phase focused on the availability of the components and their suitability to the targeted operation. The initial concept design put a lot of thought in efficiency, cost-effectiveness, and sustainability.

2.4.2. Design Phase

The structural and functional conceptualization of the machine was done at the design stage. The schematic diagrams and material specifications prepared by the researchers on the basis of the operational requirements including flow rate, mixing rate, and filtration efficiency. Ergonomics, durability and maintenance were also considered in the design. All material parameters were to be optimized to offer the best functionality at affordable prices and hence credibility and feasibility.

2.4.3. Programming Phase

The Arduino Integrated Development Environment (IDE) was used to automate the system, with the help of a C-language program. The researchers did coding and debugging to align the components as such that sensors, pumps, agitators and dosing mechanisms worked in the programmed order. The fine-tuning of the control logic was performed by trial and error until the required system flow and response was obtained.

2.4.4. Fabrication Phase

The fabrication process was in accordance with the completed design specifications. Lightweight steel was employed to weld the exoskeleton of the machine so that the structure would be stable and all the electrical and electronic components were soldered and insulated to prevent any malfunctions. The assembly was done using both the power and hand tools in order to ensure precision and compactness. During fabrication, strict control was enforced to ensure safety, accuracy and they followed the design plan.

2.4.5. Testing and Modification

The first testing was done with normal tap water to check the performance of the systems and to find the defects in the design. It was observed under conditions of functional parameters like suction rate, mixing efficiency and sensor response. Mechanical and programming modifications were done to correct identified problems like variable flow rate or sensor delay. A number of revisions of the system were carried out until the required system stability and the clarity of water were attained.

2.4.6. Final Testing

All modifications were performed and the final testing was done on rainwater as the main sample. The objective was to determine the effectiveness of the automated facility in the treatment in the context of using *Moringa oleifera* seed extract as a coagulant. The water samples were tested on the basis of turbidity, pH, TSS, DO and total coliform content. The laboratory tests were conducted at Partido State University Water Testing Facility where standardized testing processes were ensured. The overall performance of the system was determined by comparing the results of the untreated samples and the treated samples.

2.5 Data Collection and Analysis

Wastewater samples used in this study consisted of non-sewage wastewater, specifically rainwater, collected from designated catchment areas within the university premises. Collection was conducted using clean, sterilized polyethylene containers placed in open areas to avoid surface contamination. The collected samples were immediately transported to the automated treatment facility and processed within the same day to preserve their original physicochemical and microbiological characteristics. Untreated samples were retained as control specimens for comparative analysis.

Data collection was carried out through three primary methods: observation, experimental testing, and data interpretation. Observational data involved monitoring the physical characteristics of the water, including color, clarity, and odor, before and after treatment to provide qualitative indicators of treatment effectiveness.

Experimental testing constituted the core of data collection and involved laboratory analysis of both untreated and treated water samples. Treatment was performed using the developed Arduino-based automated system, where *Moringa oleifera* seed extract was introduced through an automated dosing mechanism. The system controlled the stages of coagulation, flocculation, sedimentation, and filtration under pre-set operational parameters. Following treatment, samples were analyzed to determine changes in water quality parameters, including turbidity, pH, total suspended solids (TSS), dissolved oxygen (DO), and total coliform count.

The resulting data were organized, tabulated, and quantitatively analyzed to assess treatment efficiency by comparing pre-treatment and post-treatment values. Data interpretation was conducted to establish the relationship between system performance and the effectiveness of *Moringa oleifera* as a natural coagulant. This analysis enabled the evaluation of consistency, reliability, and overall efficacy of the automated non-sewage wastewater treatment system.

3 Results and Discussions

The general performance of the automated non-sewage wastewater treatment system with *Moringa oleifera* seeds is described in Table 1 that indicates that the treated water was always compatible with the Philippine National Standards of Drinking Water (PNSDW), EPA, and WHO standards. These findings show that the automated plant was successful in the manufacture of water which was up to the national and international water quality standards.

The average PH value of the treated water was 6.53 which is within an acceptable range of 6.5-8.5. The fact indicates the natural buffering ability of *Moringa oleifera* which assists in stabilizing the chemistry of the water in the course of treatment. The small difference between pH also indicates that automated dosing and controlled mixing had an advantage over manual systems due to their capacity to be better regulated[(7)]. The turbidity was lowered to 0 FNU meaning that all suspended and colloidal particles were eliminated. This is much lower than the maximum possible value and is better than what has been reported as the manual Moringa-based treatments in the past. The finding points at the benefits of real-time automation in maintaining uniform coagulation, flocculation, and sedimentation to achieve high-quality and repeatability of performance[(7)].

The low level of total dissolved solids (21.53 mg/L), nitrite (0.1 mg/L) and phosphate (1.21 mg/L), shows that both the organic and inorganic contaminants were removed. These values were far below the standard set by the regulatory standards, and were also below those found in previous manual dosing experiments. This implies that contact time and floc settling efficiency were enhanced due to automation and at the same time there was a reduction in the variability in the operation that is prevalent in manually controlled treatment[(8)],[(?)]. Other parameters as chloride (250 mg/L), total hardness (6.3 mg/L), salinity (0%), and conductivity (32.47 μS/cm) were also at an acceptable level, which is why the treatment process did not provide excess ions or unwanted residues and the water that was treated could be reused[(6)],[(9)].

Microbiological adhesion also revealed that the levels of total coliform were substantially and reliably reduced following the treatment. This decrease can be explained by the fact that *Moringa oleifera* coagulation and flocculation inhibit the aggregation and elimination of microbial contaminant [10], [11]. Altogether, the overall physicochemical and microbiological results provided in Table 1 prove that the automated *Moringa oleifera*-based system can be successfully used to enhance the quality of water consistently and reliably.

Table 1. Physicochemical Characteristics of Treated Wastewater Using Moringa oleifera Seeds in an Automated Non-Sewage Water Treatment Facility

Parameter	Trial 1	Trial 2	Trial 3	Average	Units	Maximum Allowable Limit	Reference Limit	Remarks
pH	6.52	6.58	6.5	**6.53**	None	6.5-8.5	PNSDW	Within the Standards
Turbidity	0	0	0	**0**	(FNU)	5 FNU	PNSDW	Within the Standards
Total Dissolved Solids (TDS)	20.8	21.9	21.9	**21.53**	mg/l	600 mg/l	PNSDW	Within the Standards
Nitrite	0.005	0.008	0.009	**0.1**	mg/l	3.0 mg/l	PNSDW	Within the Standards
Phosphate	1.22	1.21	1.21	**1.21**	mg/l	3.0 mg/l	EPA	Within the Standards
Chloride	250	250	250	**250**	mg/l	250 mg/l	PNSDW	Passed
Total Hardness	6.33	6.29	6.29	**6.3**	mg/l	300 mg/l	PNSDW	Passed
Salinity	0%	0%	0%	**0%**	(ppm)	0.1	EPA	Passed
Conductivity	32	32.7	32.7	**32.47**	(uS)	250 uS	WHO	Passed

4 Conclusions

This research has managed to prove the construct and test of an Arduino-controlled automated system of water purification (non-sewage) of water using *Moringa oleifera* seeds as a natural coagulant. The system also produced a consistent water of national and international standards with the most important physicochemical parameters maintaining a marked improvement pH was at 6.53, turbidity was at zero (0 FNU), total dissolved solids was at 21.53mg/L, nitrite was at 0.1mg/L, phosphate was at 1.21mg/L. The system was in marked contrast to former manual based treatments using *moringa* that recorded residual turbidity (1-2). This is the originality of the study since natural biocoagulation is combined with sensor-based automation, which reduces human error, maintains uniform dosage and mixing and improves sedimentation performance.

The practical benefits of the study include: the study refers to the combination of eco-friendly coagulants and automation as a low-cost and environmentally friendly solution, which can be scaled to serve the needs of small-scale or local level. The fact that it can be reproducible in repeat trials is also indicative of its reliability as a treatment method. However, the research is restricted to experimental studies at laboratory level with rainwater as the major source of water; non-sewage wastewater variability in the real world can also cause some challenges. Future studies may examine the system in relation to more challenging wastewater streams, also examine hybrid treatment as a larger range of contaminants can be removed, and investigate the long-term viability of *Moringa* seed performance in continuous operation.

Overall, the study introduces a new and sustainable strategy of automated water treatment, showing that the integration of natural coagulants and regulated automation can become better than the traditional manual methods, offering a good chance on the safe and replicable water purification in the resource-restricting conditions.

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