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REUSABLE COCONUT WASTE DERIVED ADSORBENT FOR EFFECTIVE ELIMINATION OF AS (III) AND CR (VI) FROM AQUEOUS SOLUTIONS

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ABSTRACT

This research explores the use of dried coconut meat, a by-product of coconut milk processing, as a cost-effective and sustainable adsorbent for removing arsenic and chromium from water. Comprehensive characterization revealed that the material contains notable carbon content, relevant surface functional groups, and a specific surface area of 6.97m²/g, indicating its suitability for adsorption applications. Batch experiments were conducted to evaluate the adsorbent's efficiency under varying conditions. The highest removal efficiency for both metals was achieved at pH 6, with adsorption equilibrium attained after 7 hours. Kinetic studies highlighted that the adsorption followed a pseudo-second-order model, suggesting that the rate-limiting step is likely governed by film diffusion. Additionally, the adsorbent showed strong regeneration potential, retaining much of its adsorption capacity after multiple reuse cycles. The research highlights the environmental and economic advantages of utilizing agricultural waste for water purification, supporting efforts toward sustainable resource use and pollution control. It introduces a novel application of dried coconut meat**,** a by-product from coconut milk production, effectively turning waste into a valuable resource and aiding in sustainable waste management practices.

Keywords: Coconut Meat, Adsorption, Heavy Metal Removal, Arsenic, Pseudo Second Order Kinetics, Regeneration.

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INTRODUCTION

Did you know that even tiny concentrations of heavy metals in water, just a few parts per billion can lead to severe health problems, including cancer, liver failure, and neurological disorders?[1] Certain rocks, groundwater, and ocean sediments naturally contain both chromium (Cr) and arsenic (As III).[2] Additionally, industrial activities including manufacture of paint, leather, batteries, paper, medicines, electroplating, and oil refining release these metals into environment.[3] Given that they are persistent and non-biodegradable, they present serious risks to environment and human health.[4] Sleep disturbances and liver and brain damage, including Wilson's disease can result from prolonged exposure to arsenic.[5] Cancers of the lungs, bones, and nasal passages, as well as skin disorders like dermatitis, can result from exposure to chromium.[6] The Environmental Protection Agency (EPA) has developed maximum allowable levels for As(III) and Cr(VI) at approximately 1.30 and 0.10mg/L, correspondingly.[11] A lot of methods like osmosis, coagulation, electrochemical precipitation, ion exchange are less practical since they are expensive, ineffective, or produce hazardous consequences.[7] Adsorption's ease of use, versatility, affordability, and absence of hazardous consequences make it one of the best techniques for eliminating heavy metals.[1,8] Adsorbents that include zeolite, silica, and activated carbon can additionally remove As(III) and Cr(VI). The need for less-priced and more effective substitutes is highlighted by the fact that

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these materials are frequently costly and necessitate intricate preparation.[9] Adsorbents that are inexpensive, readily available, and require little processing are cost-effective. These materials are frequently leftovers from other industries.[10]Agricultural waste has drawn interest recently as a possible adsorbent. Research indicates that agricultural waste can efficiently eliminate heavy metals with little processing. Successful applications of materials such as fruit peels, tomato waste, sesame straws, rice husks, and algae have demonstrated their potential as economical and effective substitutes.[6,10] Research on the extraction of heavy metals from coconut waste materials, including pith, shells, leaves, and fibre, has been substantial.[5] However, little is known regarding the application of dried coconut meat (DCM) as an adsorbent. The objective of current research is to evaluate DCM's elimination capacity for As(III) and Cr(VI) as a low-cost, eco-friendly adsorbent, which remains largely unexplored.[11] Based on variables including contact time and solution pH, adsorption efficiency was evaluated. To comprehend adsorption kinetics, the underlying mechanism, and the adsorption rate, experimental data were also examined.[4,7] This research directly supports SDG-6 (Clean Water and Sanitation) by exploring a sustainable method to enhance water quality by promoting the valorisation of agricultural waste. By turning an underutilized by-product into a valuable resource, the study aligns with global efforts toward resource efficiency, environmental protection, and improved public health.[10,11]

EXPERIMENTAL

Collection of Chemicals and Raw Materials

The coconut milk processing unit provided the dried coconut meat. Anil Scientific Laboratory from the local area provided the chemicals utilized in this investigation, which included sodium hydroxide (NaOH, 99.99%), potassium dichromate ($K_2Cr_2O_7$, 99.50%), nitric acid (HNO_3, 99.99%), and sodium arsenite ($NaAsO_2$, 99.50%).

Preparation of Adsorbents

Fresh dried coconut meat (DCM) was obtained from the extraction of the coconut milk industry. To remove any residual impurities, it was carefully washed using distilled water. The cleaned DCM was then placed under direct sunlight for approximately two days to allow for natural moisture evaporation. After drying, the material was ground utilizing a mechanical grinder and passed via a sieve to achieve a uniform particle size ranging from 100 to 150 µm. The resulting powder was rinsed once again with distilled water to eliminate any remaining fine particles. It was then oven-dried at 70 °C for 24 hours to ensure complete dehydration. Finally, the processed adsorbent was stored in an airtight desiccator at room temperature to maintain its dryness and stability until further use in adsorption tests.

Adsorbents Characterization

Using Surface area Porosimetry, the external space of DCM was observed. The Fourier Transform Infrared Spectroscopy (FTIR) method has been employed for determining functional groups on DCM. Additionally, the surface structure of the adsorbent has been investigated by Scanning Electron Microscopy (SEM), as illustrated in Fig.-1.

Detection Method

Stock solutions at a concentration of 1,000 mmol/L were initially prepared using sodium arsenate ($NaAsO_2$) for Arsenic (As(III)) and potassium dichromate ($K_2Cr_2O_7$) for Chromium (Cr(VI)). These solutions were then diluted to the required working concentrations for use in the adsorption experiments. In each trial, 25mL of the diluted metal solution was poured into a 125mL Erlenmeyer flask. Solution pH was adjusted to the desired level using either dilute nitric acid (HNO_3) or sodium hydroxide (NaOH). A precise quantity of 25 mg of dried coconut meat (DCM) adsorbent was then introduced into the flask. The contents were mixed using a magnetic stirrer set to 300 rpm, with the temperature maintained at 25 ± 1.0 °C throughout the process. The mixture was left to react for 24 hours to allow sufficient time for adsorption equilibrium to be achieved. Subsequently, the solution has been passed through a 0.45µm syringe filter to separate the adsorbent. Remaining concentrations of arsenic and chromium in filtered solution were then quantified employing an Atomic Absorption Spectrophotometer.
Applying Equation (1), the adsorption capacity, Q(mmol/g), has been calculated.

$$Q = (\boldsymbol{C}x - Cy)\left(\frac{v}{m}\right) \quad (1)$$

In the above equation, Cx and Cy represent the first and final concentrations of heavy metals (mmol/L), V represents the volume of heavy metal solution (L), and m represents the mass of DCM adsorbent (g). Tests have been conducted under altered conditions to examine. The impact of agitation time, 24 hours, and solution pH ranging from 2 to 6.

Regeneration Study

To remove heavy metals, the experiment utilized DCM adsorbent that underwent an additional adsorption-desorption cycle. The spent adsorbent was oven-dried for 24 hours at 80 ± 0.5°C, then it was stirred in a 0.1 M HNO_3 solution in a volume corresponding to the mass of the adsorbent. The adsorbent was filtered and then oven-dried for a further twenty-four hours at the same temperature. After regeneration, the DCM was utilized for a second adsorption cycle with solutions of As(III) and Cr(VI) for about a day. To evaluate its efficacy and reusability, its adsorption capability was finally examined.

RESULTS AND DISCUSSION

Characterization of DCM Adsorbent

The specific exterior area of the DCM adsorbent was observed as 6.97m²/g. According to Surface Area and Porosimetry (SAP) analysis, the adsorbent's total pore volume is 69.12 × 10^{-4}cm³/g, and its pore size is 5.52 nm. The DCM adsorbent's elemental composition was determined the oxygen (51.73%), sulphur (0.92%), nitrogen (2.00%), hydrogen (8.24%), and carbon (59.22%). At ×300 and ×500 magnifications, Fig.-1 depicts the DCM adsorbent's surface morphology, showing a smooth texture with little pore development and uneven shapes and sizes.

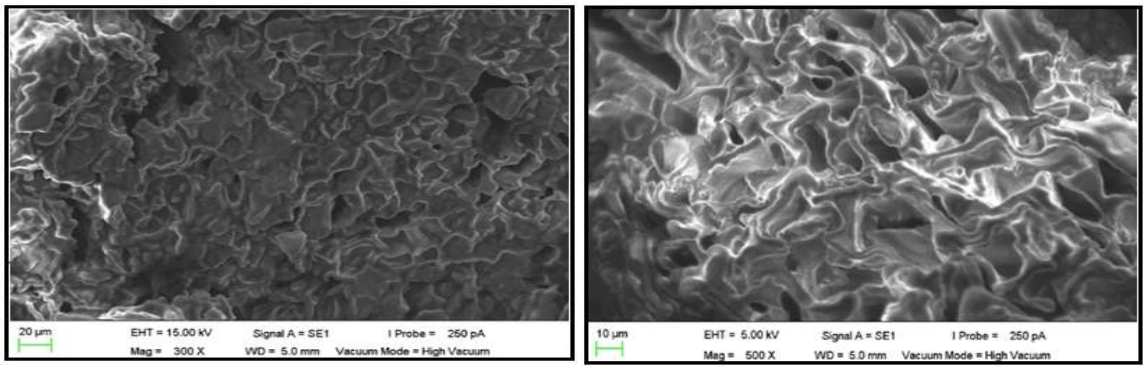

Fig.-1: Surface Morphology of DCM Adsorbent at 20 and 10 µm

The FTIR analysis of DCM adsorbent, shown in Fig.-2, reveals key functional groups associated with cellulose, hemicellulose, and lignin in coconut waste. Hydroxyl (O-H) stretching appears in the 3,488–3,300 cm^{-1} range, while alkane (C-C) stretching is observed between 3,000–2,800 cm^{-1}, indicating the occurrence of hemicellulose and water on the surface. This contributes to the hydrophilic nature of the surface, which facilitates metal ion access and binding. Peaks at 1,899 and 1,688 cm^{-1} correspond to C=O (esters) and C=C (alkenes) stretching. These groups can participate in electrostatic interactions or coordinate bonding with metal ions, enhancing the adsorption capacity. Additionally, secondary alcohol (C–O) stretching at 1,488 cm^{-1} and alkane (C–C) bending in the 1,200–1,100 cm^{-1} range are also identified. This contributes to metal ion chelation.

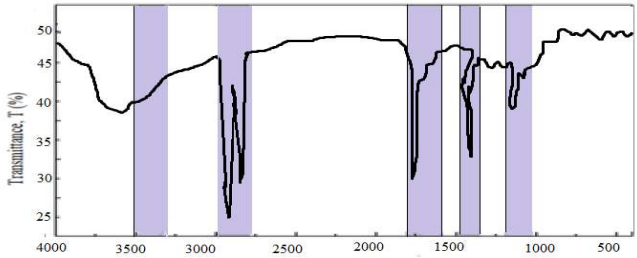

Fig.-2: Spectra of DCM Adsorbent

pH Effect

The pH of the solution significantly affected the adsorption of As(III) and Cr(VI) by DCM, which additionally impacted the external charge of the adsorbent and metal ion speciation. This study examined how initial pH, extending from 2 - 10, impacted the adsorption ability of DCM. Fig.-3 illustrates the relationship between adsorption ability and the initial solution pH. With increasing pH, DCMs can adsorb As(III) and Cr(VI), increasing. High H^+ concentration at pH 2 resulted in low adsorption (Cr(VI): 0.01mmol/g, As(III): 0.05mmol/g), which impeded metal ion binding by electrostatic repulsion. As pH rose, adsorption improved, peaking at pH 6 (Cr(VI): 0.149 mmol/g, As(III): 0.32 mmol/g) due to reduced H^+ ions, minimizing repulsion and enhancing metal ion capture. However, as the pH of the solution increased beyond a specific limit, DCM's adsorption ability for As(III) and Cr(VI) decreased. This primarily decreases due to hydroxide precipitate formation, such as $Cr(OH)_3$ and $As(OH)_3$, which reduces the number of free metal ions available for adsorption. The pHpzc of DCM was 5.40, with a positive charge below this pH and a negative charge above it. For As(III) and Cr(VI) adsorption, pH 6 has been optimal. These findings suggest that the adsorption efficiency of DCM is strongly governed by pH-dependent surface charge interactions and metal ion speciation.

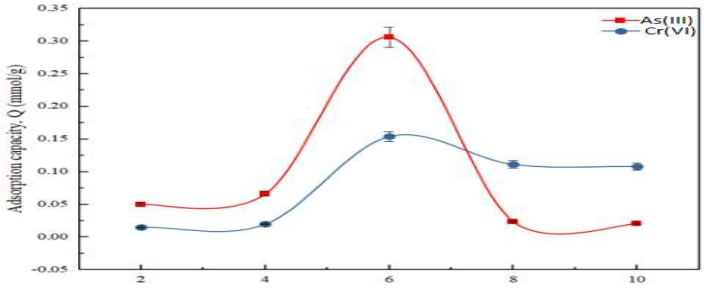

Fig.-3: pH Effect on Arsenic and Chromium

Effect of Contact Time

The effect of agitation time on the adsorption capacity of DCM adsorbent for As(III) and Cr(VI) in aqueous solutions has been evaluated over 24 hours. With longer agitation times, DCM adsorbent's adsorption capability for both heavy metals rose, as seen in Fig.-4. Furthermore, it was shown that As(III) ions had a usually better removal efficiency than Cr(VI) ions, following an increase rapidly in the first hour, As(III) and Cr(VI) adsorption onto DCM stabilized at equilibrium between 7-8 hours and remained constant for 24 hours. The rapid initial adsorption indicates the abundance of available active sites on DCM, which gradually become saturated over time. Equilibrium at 7–8 hours suggests that extending agitation beyond this point does not significantly enhance adsorption, ensuring process efficiency.

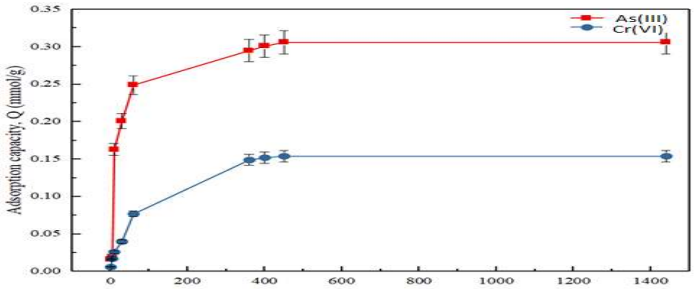

Fig.-4: Contact Time Effect on Arsenic and Chromium Adsorption

Kinetic Study

Adsorption kinetics was analysed using PFO, PSO, and Elovich models. PFO suggests site-specific physical adsorption, PSO indicates chemical adsorption with covalent bonding, and Elovich accounts for ion interactions and site-specific adsorption. Table-1 illustrates the kinetic model parameters, with the PSO model best fitting the data. Its R^2 values were closest to 1, and Q_{exp} closely matched Q_{theory}, confirming its validity. This indicates that Covalent bonds are formed at heterogeneous active sites during the As(III) and Cr(VI) adsorption process onto DCM, which attain equilibrium when adsorption and desorption rates are equal.

Table-1: Equilibrium and Kinetic Adsorption for As(III) and Cr(VI) onto DCM

Model Type	Equation linearized	Parameters	As(III)	Cr(VI)
Pseudo-First-Order (PFO)	$In(Q_e - Q_1) = (Q_e - K_1\ t)$	Adsorption Ability (Q_{exp}) (mmol/g)	0.162	0.299
		Theoretical Adsorption Capacity (Q_{theory}) (mmol/g)	0.154	0.198
		Rate Constant (K_1) (min^{-1})	0.011	0.099
		Correlation Coefficient (R^2)	9.100	0.890
Pseudo-Second-Order (PSO)	$\frac{t}{Q_1} = \frac{1}{K_2\ Q_e^2} + \frac{1}{Q_e}$t	Adsorption Capacity (Q_{exp}) (mmol/g)	0.165	0.286
		Theoretical Adsorption Capacity (Q_{theory}) (mmol/g)	0.162	0.321
		Rate Constant (K_2) (mmol/min)	0.189	0.192
		Correlation Coefficient (R^2)	1.000	1.000
Elovich Model	$Q_t = \frac{1}{\beta} In(\alpha\beta) + \frac{1}{\beta} In\ t$	Initial Adsorption Rate (α) (mmol/g·min)	0.011	0.068
		Desorption Constant (β) (g/mmol)	37.810	20.912
		Correlation Coefficient (R^2)	0.921	0.798

Equilibrium and kinetic constants for adsorption of As(III) and Cr(VI) onto DCM have been displayed in this table, with the PSO model showing the best fit (R^2 = 1.000) and a close match between Q_{exp} and Q_{theory}. The superior fit of the PSO model suggests strong interactions at heterogeneous active sites, reinforcing DCM's potential for stable and efficient heavy metal removal.

Diffusion Kinetics

Adsorption kinetics was influenced by diffusion or a surface response mechanism. The diffusion process involved three steps: bulk diffusion (movement from solution to adsorbent surface), film diffusion (transfer across the liquid boundary layer), and intraparticle diffusion (penetration into adsorbent pores). The Weber-Morris plot Equation (2) analysed this mechanism.

$$Q_t\ = K_{id}\ t^{0.5}\ + c \qquad (2)$$

The amount of adsorbate retained at a certain time is indicated by the adsorption capacity, which is expressed as Q_t (mmol/g). K_{id} stands for the intraparticle diffusion constant. Three different stages of the Weber-Morris plot were investigated. Instantaneous or external surface adsorption was used in the initial stage. A phase of slow adsorption ensued, during which intraparticle diffusion was the primary factor. Finally, a slower adsorption rate indicated the arrival of the equilibrium phase. Intraparticle diffusion has been evaluated as the rate-limiting phase employing the Weber-Morris plot. Multiple diffusion pathways have been demonstrated by 2 linear segments in the adsorption of As(III) and Cr(VI). Film and effective diffusion coefficients, with the lower value indicating control, were identified. The film diffusion coefficient was calculated using Fick's Law in Equation (3).

$$\frac{Q_t}{Q_e} = 6\left(\frac{D_f}{\boldsymbol{\pi\ R\ p^2}}\right)^{0.5} t^{0.5} \qquad (3)$$

The ratio Q_t/Q_e was plotted against $t^{0.5}$ using Equation (3) to analyze adsorption. The DCM adsorbent's radius was 0.015 cm, with film diffusion constants of 1.812×10^{-7} cm^2/min for As(III) and 1.190×10^{-7} cm^2/min for Cr(VI). The effective diffusivity constant (D_{eff}) was determined using Boyd plot equations (Eqn.-4) and Eqn.-5).

$$Bt = -0.4977 - 1n(1-F), Fvalue > 0.85 \qquad (4)$$

$$Bt = \left(\sqrt{\pi} - \sqrt{\pi - \left(\frac{\pi^2 F}{3}\right)}\right)^2, Fvalu < 0.85 \qquad (5)$$

$F=Q_t/Q_e$ was used to plot B_t against time to determine Deff. Equation (6) has been employed for determining the effective diffusion coefficient for As(III) and Cr(VI) adsorption based upon the Boyd plot's slope.

$$s = \pi^2 \left(\frac{D_{eff}}{R'^2{}_p}\right) \quad (6)$$

R^2 p is the radius of the DCM particle (0.015cm), and S is the slope of the Boyd plot. The effective diffusivity coefficient (D_{eff}) was 1.819×10^{-7} cm²/min for As(III) and 2.102×10^{-7} cm²/min for Cr(VI). As D_{eff} values were lower than D_f. The lower D_{eff} compared to D_f indicates that intraparticle diffusion, rather than film diffusion, governs the rate-limiting step in the adsorption procedure. This emphasizes the significance of pore structure and internal transport in controlling the overall adsorption efficiency of DCM.

Regeneration Studies

Three adsorption-desorption cycles have been employed for evaluating the regeneration potential of spent DCM adsorbent to remove As(III) and Cr(VI). Adsorption capabilities for Cr(VI) and As(III) dropped with each cycle, from 0.05-0.02mmol/g and 0.150-0.075mmol/g, respectively, as illustrated in Fig.-5. This trend indicates a gradual decline in adsorption efficiency over repeated use. The decline in adsorption capacity may result from incomplete desorption of metal ions, reducing available binding sites in the adsorbent. As a result, fewer active sites are available in subsequent cycles. Previous studies support DCM's ability to undergo multiple regeneration cycles with stable performance.[8] For eliminating As(III) and Cr(VI), DCM is a viable option given its low cost and reusability. It could be incinerated or landfilled in a landfill, where it will degrade organically.

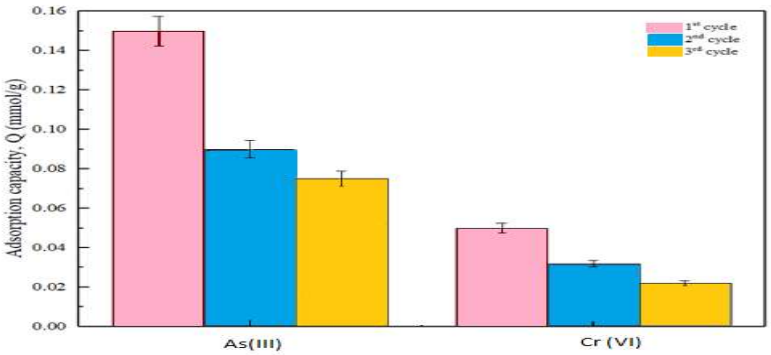

Fig.-5: Regeneration of DCM Adsorbent

Table-2: As(III) and Cr(VI) Removal by Different Agricultural Wastes

Waste Materials	Heavy metals	Adsorption rate (mg/g)
Fruit peels	As(III)	1.41
	Cr(VI)	0.92
Rice husk	As(III)	0.87
	Cr(VI)	0.70
Sawdust	As(III)	0.75
	Cr(VI)	0.55
Coconut coir pith	As(III)	2.66
	Cr(VI)	3.97
Coconut shell	As(III)	2.99
	Cr(VI)	3.99
Coconut husk	As(III)	1.99
	Cr(VI)	1.67
Coconut meat	Cr(VI)	19.99
	As(III)	14.78

Absorbent Cost Evaluation

Commercial adsorbents like zeolite and activated carbon are expensive due to energy-intensive production and high electricity use, making them less viable for widespread industrial application. To find cost-effective alternatives, this study explores dried coconut meat (DCM), a by-product of the coconut milk industry. Commonly discarded in landfills, DCM poses environmental concerns but offers promise as a low-cost, energy-efficient adsorbent with minimal processing and good reusability. Table-2 illustrates

that DCM performed better than other untreated agricultural wastes, including fruit peels, rice husk, and coconut by-products, with adsorption capacities of 14.78mg/g for As(III) and 19.99mg/g for Cr(VI). These findings underscore its effectiveness and affordability in heavy metal removal. These studies directly support SDG-6: Clean Water and Sanitation by demonstrating that dried coconut meat, a low-cost and sustainable adsorbent, effectively removes toxic metals like As(III) and Cr(VI) from water. Promoting affordable, energy-efficient water treatment using agro-waste contributes to improving water quality and advancing sustainable water resource management.

CONCLUSION

This study demonstrates the effectiveness of dried coconut meat (DCM) as an economical and efficient biosorbent for eliminating arsenic As(III) and chromium Cr(VI) from contaminated water. With a surface area of 6.97 m^2/g and an irregular porous structure, DCM contains functional groups from lignin, cellulose, and hemicellulose that aid in heavy metal adsorption. The optimum adsorption occurred at pH 6, reaching equilibrium within 7 hours. The highest recorded capacities were 0.32 mmol/g for As(III) and 0.149 mmol/g for Cr(VI), with kinetic analysis confirming that chemisorption, following a pseudo-second-order model, governs the process. DCM proves to be a renewable, cost-effective, and eco-friendly substitute to conventional adsorbents. Its consistent performance under various conditions and its reusability over multiple cycles make it suitable for industrial wastewater treatment while promoting waste valorization.

To further enhance its performance, future work could focus on thermal treatment of DCM to increase adsorption efficiency and regeneration. Additionally, incorporating DCM into decentralized water treatment systems can improve water accessibility in underserved or rural communities. This approach contributes directly to SDG-6 by improving water quality (Target 6.3) through affordable, sustainable technology. It encourages the recycling of agricultural waste and offers a scalable, green solution for clean water in low-resource settings.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHORS CONTRIBUTION

The present work is related to *SDG-6: Clean Water and Sanitation*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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