

## Appraisal of Characterization and Adsorption Isotherm in the Bioremediation of Cu and Zn Ions from Aqueous Solutions Exploiting Unmodified Corn and Coconut Husk

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### Abstract

Environment is contaminated by heavy metals has emerged as a substantial globally. Conventional remediation methods have proven inadequate and costly in addressing this issue. Hence, there is a pressing need to discover bio-remediation as a cost effective, effectual, and environmentally, a substitute for heavymetal removal. This work investigates the adsorption behaviour of Corn Husk (CH) and Coconut Husk (CCH), an inexpensive adsorbent, towards Cu and Zn ions for potential application in wastewater treatment. The physico-chemical variables of unmodified CH and CCH were appraised, and batch experimental methods were employed to study variables like pH, contact time, size of particle, and preliminary content of metals. The impact of solution pH on metals uptake by the adsorbent was investigated on the pH range of 3 to 8, revealing optimal removal efficiencies at pH 6 for Cu and pH 5 for Zn. Equilibrium adsorption times were determined to be 80 minutes for Cu and 60 minutes for Zn ions onto CH and CCH. adsorption volumes is conforming to mono-layer coverage, attained from the Langmuir plots were 4.792 mg/g and 4.594 mg/g respectively for Cu and Zn metals onto the CH and 4.771 mg/g and 4.400 mg/g for their adsorption onto CCH. Experimental values were confirmed to the Langmuir model and Freundlich model, with the Langmuir model providing the best fit. The CH based adsorbent was generally found to have an increased capacity of adsorption of the metal contents than Coconut husk (CCH). These findings underscore the strength of Corn husk as an active adsorbent to extract cationic heavymetal contents from industrial effluents.



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
### Keywords

Adsorption Isotherm;  
Bio-sorbents;  
Coconut Husk;  
Corn; Model.

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## Abbreviations

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AAS	atomic absorption spectrophotometer
BD	Bulk density
BEAS	Batch equilibrium adsorption studies
CCH	Coconut Husk
CH	Corn Husk
FTIS	Fourier Transform Infrared Spectroscopy
mg/g	Milligrams per grams
mg/L	Milligrams per liter

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## Introduction

The contamination of the environment through the exhaust of toxic substances in wastewater is an important issue affecting both public health and environmental well-being. Among trace pollutants, heavy-metals stand out as particularly hazardous.<sup>1,2</sup> Their presence has tainted numerous bodies of water, posing risks to human-health and other organisms. The release of heavy-metals poses a considerable hazard due to its toxicity, tendency to entering in the food chain, and long-lasting influence on the environment.<sup>2-4</sup> Heavy-metal pollution in water bodies will be significant environmental alarm due to industrialization and urbanization. Amongst these heavy metals, copper (Cu) and zinc (Zn) are particularly problematic due to toxicity and persistence of these in the environment. These metal ions are detrimental causes on aquatic life and human-health, necessitating effective removal strategies from contaminated water sources. Studies indicate that the toxicity resulting from metallic pollutants surpasses that of combined radioactive and organic waste.<sup>4,5</sup> Additionally, these pollutants can contribute to an increase in nutrient levels in aquatic bodies, particularly if some requires metal ions.<sup>5</sup> Furthermore, heavy-metals in wastewater can enhance the fertility of settlements and water columns, leading to eutrophication. This process, especially prevalent in surface aquatics, can ultimately expose to oxygen depletion, algal blooms, and the demise of aquatic organisms.<sup>2,3,6,7</sup>

Bioremediation, the process of using biological materials to remove or neutralize pollutants, offers a capable liquid for heavy metal removal. Agricultural waste materials, such as corn and coconut husks, have emerged as cost-effective and sustainable adsorbents due to their abundance and natural

affinity for metal ions. Utilizing these unmodified biomaterials can provide an eco-friendly and economical alternative to conventional methods of heavy metal remediation. Consequently, the management of waste-water polluted with heavy-metals remains a global concern as it is sourced from human activities and must eventually be reintroduced into getting waters and the land.<sup>6,8</sup> Traditional behaviour approaches have proven will be costly and challenging to sustainable to their capital and operating expenses, leading to the production of polluted sludge and minor waste that requires treatment prior to disposal, posing environmental hazards and risks.<sup>7,8,10,11</sup> These boundaries have prompted curiosity and research into well-organized and environmentally<sup>9,28</sup> removed of heavy-metal techniques. Adsorption comprises utilizing inexpensive, naturally occurring organic and waste materials from agricultural practices as adsorbents, which have been documented in numerous studies as effective in treating metal tainted effluents.<sup>10,12</sup> The benefits of adsorption contain its cost-effectiveness, efficacy, decreased in creation of sludge with chemical and biological, potential for adsorbent revival, and recovery of metal.<sup>11,13</sup> The accumulation of CH and CCH biomass in the ecosystem due to its disposal as waste following high consumption rates has raised environmental concerns regarding land occupation and subsequent pollution issues<sup>12,31</sup> Therefore, this study explores the potential application of recycled CH and CCH agro-waste in the remediation of Cu and Zn ion-contaminated wastewater through the adsorption phenomenon as a substitute for treatment approach.<sup>16,17-26</sup> This study goals to appraise the potential of unmodified corn and coconut husks for adsorption of Cu and Zn metals from aqueous. The characterization of these

biomaterials will be conducted to understand their structural and chemical properties that contribute to their adsorption capabilities. Furthermore, adsorption isotherm models will be applied to analyze the interaction between the metal ions and the adsorbents, providing insights into the efficiency and capacity of these substances for heavy metal removal. Identifying unique physical or chemical characteristics of unmodified corn and coconut husk that contribute to effective adsorption of Cu and Zn ions. Utilizing unmodified, natural materials for bioremediation, which is both cost-effective and environmentally sustainable

## Materials and Methods

### Preparation of Adsorbent

The CH and CCH were sourced from a local agricultural land in agricultural land outside Davangere city in Karnataka State, India. Both sample materials underwent a rigorous cleaning process involving tap-water and subsequent wetting with double condensed water to extract surface dust and contaminations.<sup>30,3,32</sup> Following this, the husks were air-dried and dehydrated using oven (80°C) until a consistent mass was attained. The desiccated biomass was milled and separated through an electromagnetic mesh to attain specific sizes smaller than 250µm. Finally, the desiccated bio-mass was stored in airtight polyethylene bags to control it from moisture and prepare it for appraisal.<sup>34,36</sup> It's significant to reminder that the adsorbent was used in its natural state with-out any modifications.<sup>37,40</sup>

### Preparation of Stock Solutions

Analytical grade compounds were employed in the preparation of chemical solutions utilized in the work. A stock aqueous of Cu and Zn (1 liter) was created by taking 2.51 g of CuSO<sub>4</sub> and 0.44 g of ZnSO<sub>4</sub> separately in one litre of double distilled water. Subsequent standards of the trace-metal ions prepared through serial method from the synthetic stock solution. The pH of aqueous was adapted by 0.1 M acid HCl and 0.1 M alkaline NaOH.<sup>50,52</sup>

### Moisture Content

Estimation of moisture content involved placing 5 grams of the substance (CH and CCH) into a separate crucible, followed by heating it in an oven for a consistent 5-hour period at 105°C. After heating, the sample was promptly transferred to a desiccator to

prevent moisture absorption from the surrounding atmosphere. Subsequently, the sample was re-weighed, and same phenomenon was repetitively done for consistent quantity was achieved. The variance in weight after heating represents the moisture in the adsorbents (CH and CCH), which was noted as 23% and 24% respectively.

$$\% \text{ of Moisture} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad \dots(1)$$

W<sub>1</sub> = weight of bowl, W<sub>2</sub> and W<sub>3</sub> = Initial and final weight of sample respectively

### Loss of Mass

The process of determining the loss of weight upon ignition involved initially weighing 10g of the adsorbent (comprising CH and CCH) and placing it in a furnace set at a consistent temperature of 580°C for duration of 2 hours. Following the heating process, the sample was taken out and allowed to cool within a desiccator.<sup>42,43</sup> The remaining product was subsequently taken, with the variance in weight indicating the quantity of organic content within the weighed sample. This series of steps are repeatedly done for four times to get accuracy and reliability.

### Bulk Density (BD)

BD of both CH and CCH samples was evaluated adopting Archimedes' method. Initially, a 10cm<sup>3</sup> computing container was taken before and after filling it with the samples to determine their mass. Afterwards, the computing container was desiccated, carefully filled inside, levelled, and reweighed. The mass of each sample crowded using gauging cylinder was appraised by the filled and empty measuring cylinder. The total volume of water was estimated by measuring the weight variance between the unfilled and filled with water in measuring cylinder. Finally, the BD estimated by adopting standard equation.<sup>35,44,47</sup>

$$\text{Bulk Density} = \frac{W_2 - W_1}{V} \quad \dots(2)$$

### Batch Equilibrium Adsorption Studies (BEAS)

BEAS was conducted using 100 mL plastic bottles following the procedures outlined by Nharingo<sup>36</sup> and Dawodu.<sup>37</sup> These experiments aimed to examine the influence of key experimental variables on the adsorption phenomenon. The critical variables scrutinized in this investigation by adopting variables

in metal contents. To maintain consistency in synthetic effluent, a constant temperature (25±2°C), volume (50 mL), and agitated (180 rpm) were maintained for 120-minute.

**Effect of Adsorbents on Dosage**

In individual 50 ml aliquots of solutions containing Cu and Zn ions at a concentration of 200 mg/l, biomass quantities ranging between 0.1 and 1 g were added to 100 ml plastic containers. The solutions were then agitated applying 180rpm in a shaker for 120 minutes at a 25±2°C temperature of and a 6.0 pH. Subsequently, the mixtures underwent filtration, and the residual metal ions were appraised using an AAS.<sup>48,49</sup>

**Effect of pH**

The impact of pH on the % of removal of Cu and Zn metal contents by CH and CCH was explored adopting initial aqueous solutions containing 200 mg/l of Cu and Zn ions. Each 100 ml plastic bottle received in different measurements of 50 ml of the 200 mg/l Cu and Zn ion solutions. pH adjusted range between 3 to 8 adding 0.1 M strong acid (HCl) and 0.1 M Strong base (NaOH) solutions. Subsequently, 1g of CH and CCH are separately mixed to each plastic bottle consisting metals by varied in pH. The mixtures were placed in an electric shaker operating (180 rpm) for 120 minutes at a temperature (25±2°C). Finally, cleaned samples are subjected to analysis for residual metal contents.<sup>53,54,55</sup>

**Effect of Initial Metal Soncentrations**

An initial content of metal ions was estimated under optimal settings. This involved blending 1 gram of SH powder with 50 milliliters of solutions containing Cu and Zn ions with changing initial contents ranged between 50 and 200 milligrams per liter at a pH of 6. The experimentations appraised at a controlled temperature (25 ± 1°C) with a constant rpm (180) for duration of 120 minutes.<sup>56,60</sup> Subsequently, the filtered samples appraised for residual metal contents using an AAS.

**Effect of Contact Time**

Batch setups were conducted over various contact durations ranging between 5 and 120 minutes. Each experiment involved mixing 50 ml of a solution contains Cu and Zn ions at a concentration of 200 mg/l with 1.0g of adsorbent at a pH of 6. The mixtures were agitated in flasks at a rate of rpm (180) and

maintained at atmospheric temperature (25±2°C). The concentration of residual metal content was appraised at different intervals using an AAS. The equilibrium times were determined to be 30 minutes for Cu and 60 minutes for Zn. Consequently, a contact time (120 minutes) selected for subsequent trails to confirm attainment of stability conditions.<sup>59,60</sup>

**Effect of Adsorbent Particle Sizes**

Each 50 ml of a solution containing Cu and Zn ions of 200 mg/l was placed in separate 100 ml plastic containers. Bio-mass particles varying in size from 1000 to less than 250µm were added to each bottle individually. Mixtures are agitated on a shaker at rpm (180) for 120 minutes at a temperature (25±20C) and pH at 6. After agitation, filtered mixtures and the residual metal contents were appraised using an AAS Throughout the experiments, one changed variable and others remained constant.<sup>57,58</sup> Filtration occurred at the conclusion of each specified contact time, and the concentration of metal contents in the filtrate was appraised adopting the same AAS. All Setup conducted frequent twice, average value taken. The quantity of adsorption of metal contents adsorbed per-unit-mass was determined applying eqn 1 and 2.<sup>38</sup>

$$Q = \frac{V(C_i - C_e)}{W} \dots(3)$$

$$\%Sorption = \frac{C_i - C_e}{C_i} \times 100 \dots(4)$$

Q=the quantity of adsorbed from the solution, V=Volume of the adsorbate  
 C<sub>i</sub> and C<sub>e</sub> = the concentration before adsorption and at equilibrium respectively  
 W= the weight in gram of adsorbent

The proficiency of exclusion was assessed by calculating the % of sorption, as outlined in Equation (2).<sup>39</sup>

**Result and Discussions**  
**Fourier Transform Infrared Spectroscopy (FTIS) Analysis**

The surface characteristics of the bio-sorbents CH and CCH were estimated through FTIS (refer to Figures. 1 and 2). Analysis of the spectra revealed several absorption peaks, indicative of various functional groups present on these bio-sorbents, potentially involved in the extraction of metal contents

from aqueous. For CH peaks were observed at  $3461.38\text{ cm}^{-1}$  (N-H stretch),  $1640.51\text{ cm}^{-1}$  (C = C bond), and  $1192.05\text{ cm}^{-1}$  (C-O stretch), among others. CCH exhibited peaks at  $3440.16\text{ cm}^{-1}$  and various other wavelengths corresponding to different functional groups. Notably, the presence of N-H, C = C, C-O, N-H and C-H bond suggests potential sites for adsorption of Cu and Zn ions. These functional groups, possessing either  $\pi$ -electrons or lone pairs on nitrogen or oxygen, are mixed with metal ions, facilitating adsorption. Comparison of spectra suggests surface variations possibly due to carbonization of bamboo waste, leading to the occurrence of new peaks or absence of certain ones.

**Effect of pH**

The pH in liquid is a key and crucial part in adsorption studies. It affects both the binding locations on

adsorbent and interaction of metals in the aqueous. In the current study, we estimated how pH influences the adsorption of Cu and Zn contents by two different adsorbents within the pH (2 to 6), as depicted in Figure 3 and Figure 4. We did not explore pH values beyond 6.0 to control the mixture of Zn and Cu as hydroxides. Our findings indicate that the maximum adsorption of Cu and Zn on both adsorbents occurred at pH 6.0. At lower pH levels, force between metal and hydronium contents for active locations on the adsorbent on led to lower metal uptake. Previous studies reported that in highly acidic conditions, the adsorbent surface ligands may closely associate with hydronium ions, hindering the access of metal contents due to abhorrent forces. Therefore, as pH enhances, more ligands are visible, leading to the attraction of positively charged metal ions.

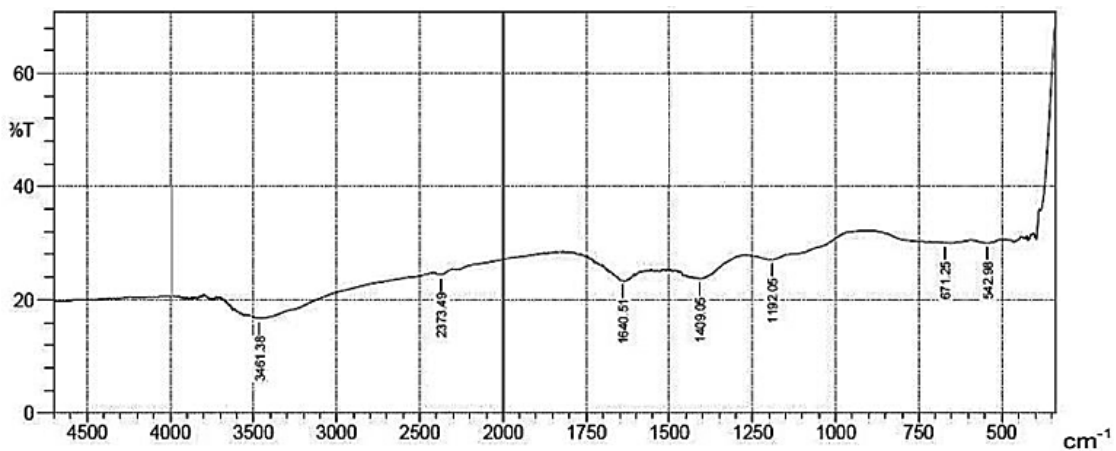


Fig. 1: FTIR spectra of CH

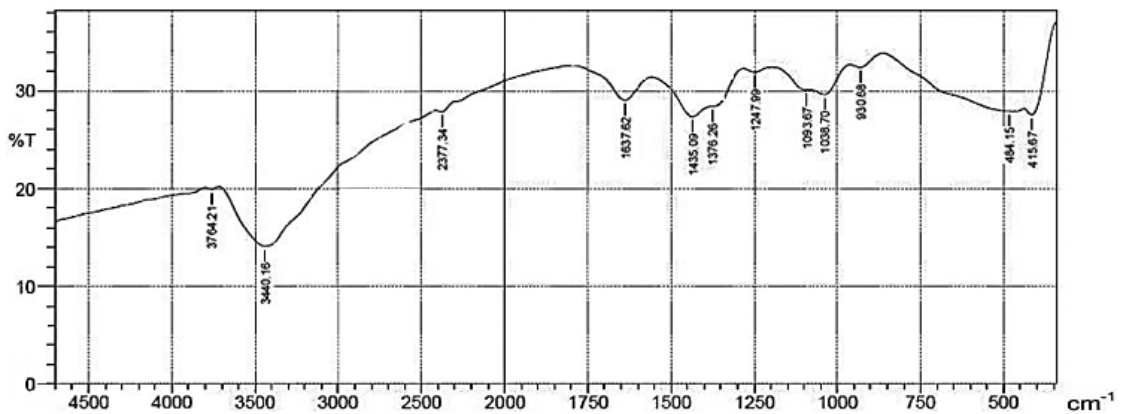


Fig. 2: FTIR spectra of CCH

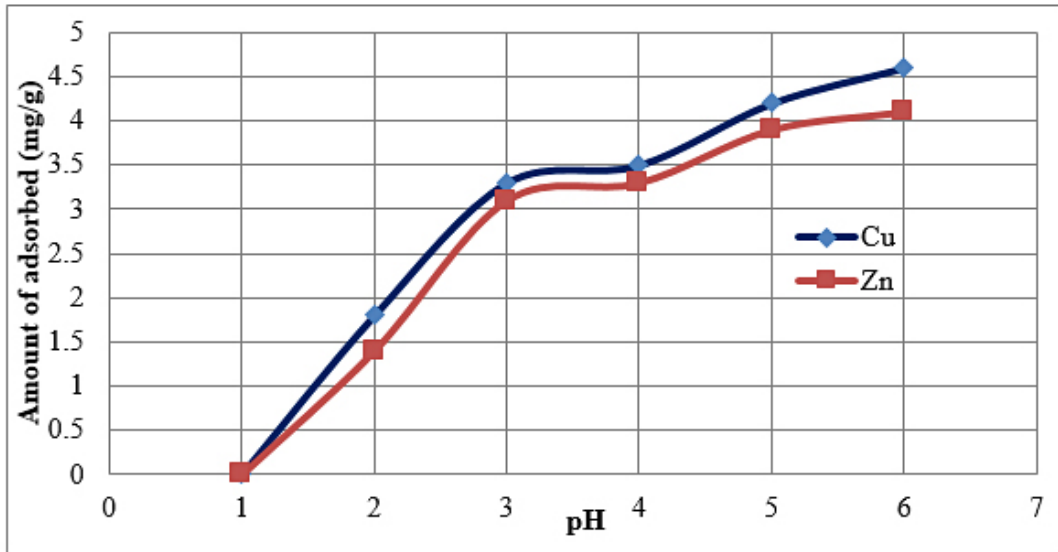


Fig. 3: Effect of pH on metals contents onto CH

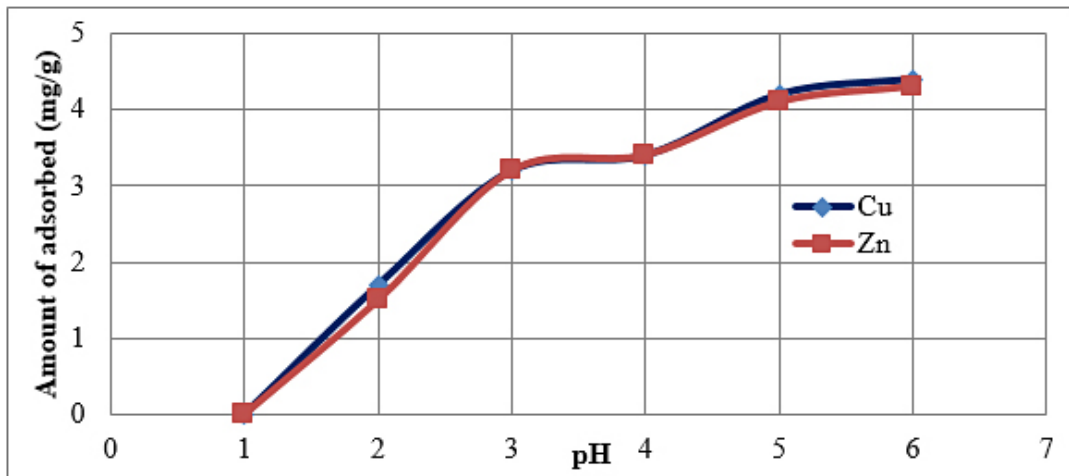


Fig. 4: Effect of pH on metal contents onto CCH

**Impact of Initial Metal Ion Content**

Figure 5 and Figure 6 illustrate that as the concentration of metal-ions increased, their adsorption onto the adsorbents also increased. Evaluating the level of metal-ion uptake revealed that Cu ions exhibited slightly superior adsorption compared to Zn ions on both adsorbents. The absence of flattening in the curves even at the highest initial content of 100 mg/L, as utilized in our investigation, suggests an incomplete occupation of the available adsorption sites by the metal ions. Furthermore, the augmentation in adsorption with

rising initial concentration is corroborated by the distribution coefficients provided in Table 1. These coefficients, representing the relation of metal contents in study stage to that in the continuous phase, delineate the relative effectiveness of the adsorbents in binding the metal ions. Notably, all distribution coefficients in Table 1 exceeded unity for the primary metal contents employed, signifying an uptake of more than 50%. However, as the initial content of metal ions increased, the distribution co-efficient generally declined. Once again, the observation stands that Cu, characterized by its

larger density and higher ionic radius (as illustrated in Table 2), Exhibited superior adsorption compared to Zn. This phenomenon can be rationalized by the tendency of metal ions to create aqua complexes upon dissolution in water,<sup>40</sup>

The aqua system is to create  $[M(H_2O)_x]^{n+}$  where 'M' represents the metal content 'n+' denotes the net variation in the system, and 'x' signifies the organisation number. The comparative uptake stages of the metal contents are inversely proportionated with their respective hydration-energies, as indicated in Table 2. Specifically, Zn with an ionic radius (0.097 nm) possesses hydration-energy (-1806 kJ mol/L), whereas Cu with an ionic radius (0.12 nm) exhibits hydration energy (-1480 kJ mol/L). Given that the

displacement in water molecules from the aqua-ion underpins adsorption dynamics, the stability of the aqua-ion emerges as a significant factor in the adsorption phenomenon. The stability of the aqua-ion, as evidenced by the hydration energies of the metal ions, is contingent upon the ion's size. Notably, ions with relatively larger sizes (and lower hydration energies) display weaker relations with water molecules compared to ions with smaller sizes (and relatively higher hydration energies). Consequently, ions with greater sizes are more adept at interacting with adsorbents since they can more-readily displace the water molecules from the aquo complex. This mechanism likely contributes to the enhanced adsorption of Cu ions over Zn ions.

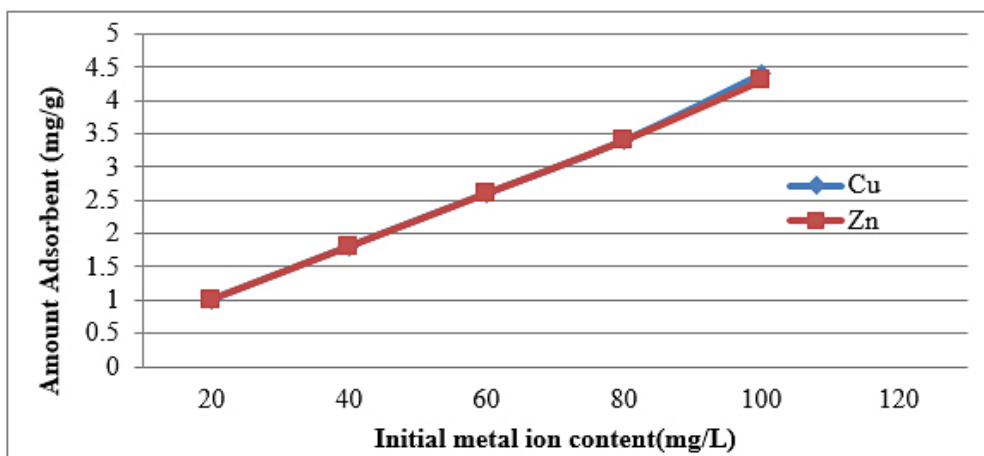


Fig. 5: Plot of sorption capacity vs initial content of metals ions onto CH

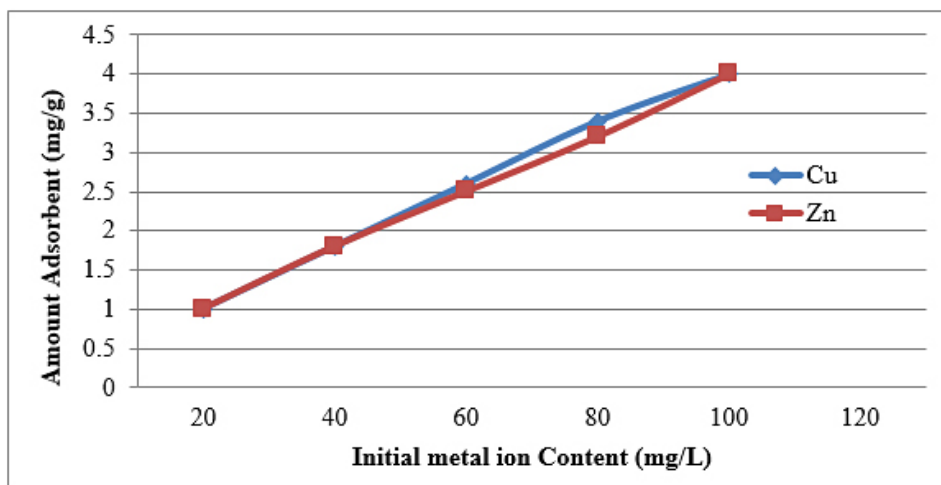


Fig. 6: Plot of sorption capacity vs initial content of metals ions onto CCH

However, it was noticed that the % of Cu and Zn ions adsorbed from the solution reduced as the primary metal content enhanced for both adsorbents (refer to Figure 7 and Figure 8). This phenomenon occurs because at lower metal contents, nearly all the metals are adsorbed. However, as the initial contents of metal-ions increase, the ratio of metals to available surface active sites also increases.

Consequently, slight adsorption will be dependent on the initial content. Despite a constant dose (mass) of the adsorbents, the total existing adsorption capacities are limited, leading to the adsorption of a similar amount of metal ions. This ultimately results in decreased removal efficiencies of the metal-ions by the adsorbents

**Table 1: Distribution coefficients for adsorption of Cu and Zn ion metals**

Initial Conc. (C0) (mg/L)	CH		CCH	
	Cu	Zn	Cu	Zn
20	88.91	50.62	42.41	25.79
40	18.52	14.56	12.72	11.42
60	8.90	7.42	12.56	11.46
80	8.41	7.42	5.99	4.05
100	6.72	5.26	4.28	3.74

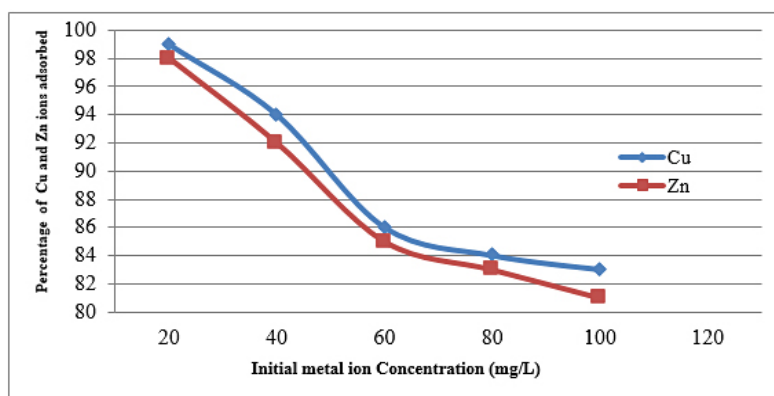
**Table 2: Physical and Chemical properties of Cu and Zn ion metals**

Element	Stable oxidation states	Density g/cm <sup>3</sup> (25°C)	Ionic radii (Å)	Hydration energy (ΔH) kJ/mol
Copper	+1 and +2	8.96	0.73	-78.20
Zinc	+2	7.14	0.79	-2049

**Adsorption Isotherms**

The assessment of adsorption equilibrium typically involves employing an isotherm equation, which characterizes the surface variability and affinity of the adsorbent at constant temperature and pH.<sup>41</sup> Adsorption equilibrium occurs when the content of

a metal content in the bulk solution (C<sub>e</sub>) reaches a dynamic equilibrium with interface. In our study, the uptake of metal ions were assessed using the Langmuir and Freundlich isotherm models and the values are presented herein.



**Fig. 7: Plot of percentage metal adsorbed vs initial conc. of the metal-ions on CH**



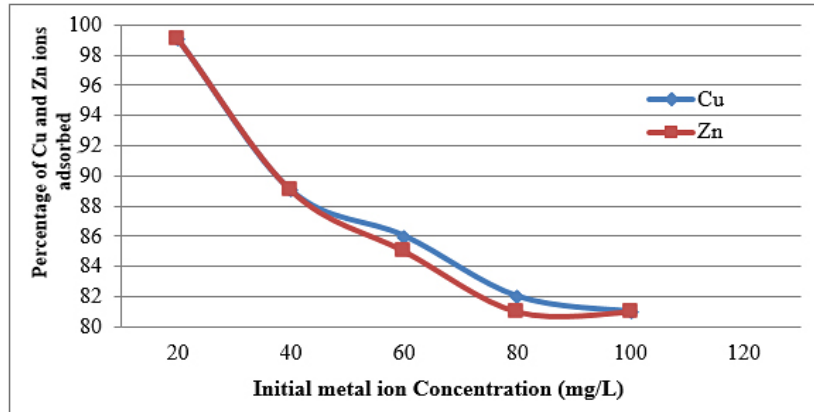


Fig. 8: Plot of percentage metal adsorbed vs initial conc. of the metal-ions on CCH

**The Equilibrium Langmuir Isotherm**

The Langmuir model describes the equilibrium partitioning of metal contents between solid and liquid stages. It operates under several assumptions:

- Metal ions undergo chemical adsorption at a set number of distinct sites.
- Each stage is capable of hosting only one ion, limiting coverage to a monolayer.
- All sites possess equivalent thermodynamic properties.
- No lateral communication among the adsorbed metal-ions.

The linearized Langmuir model equation enables the determination of the more adsorption capacity (q<sub>max</sub>) associated with monolayer coverage, along

with the Langmuir constant K<sub>L</sub> that signifies the strength of the adsorption process.<sup>42,47</sup>

$$\frac{C_e}{q_e} = \frac{1}{q_{max}K_L} + \frac{C_e}{q_{max}} \quad \dots(5)$$

The equilibrium or residual concentration after adsorption (C<sub>e</sub>) in mg/L, the adsorption-capacity of equilibrium- (q<sub>e</sub>) in mg/g, the maximum adsorption-capacity (q<sub>max</sub>) in mg/g corresponding to monolayer coverage, and the Langmuir adsorption constant (K<sub>L</sub>) are all parameters used to describe the adsorption process. The linear lines of C<sub>e</sub>/q<sub>e</sub> versus C<sub>e</sub> indicate that the adsorption process adheres to the Langmuir adsorption isotherm, as demonstrated in Figures 9 and 10.

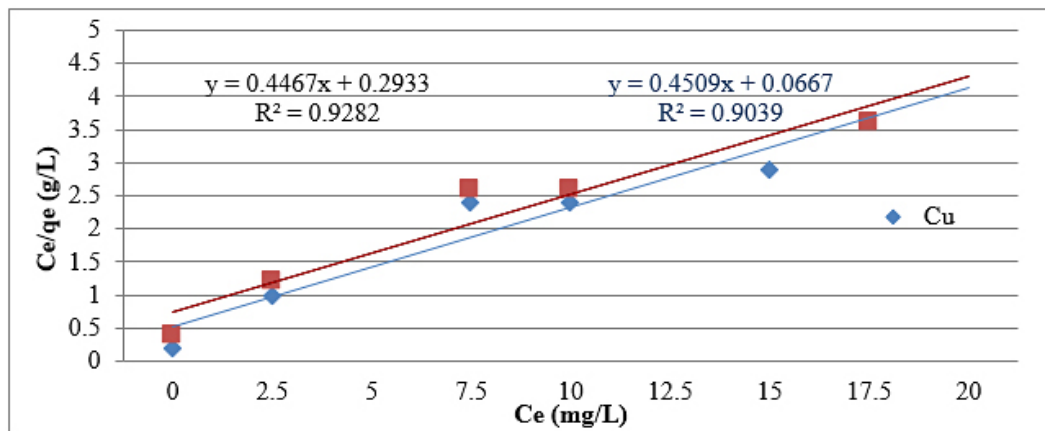


Fig. 9: Langmuir model line of Ce/qe vs Ce of the metal-ions on the CH

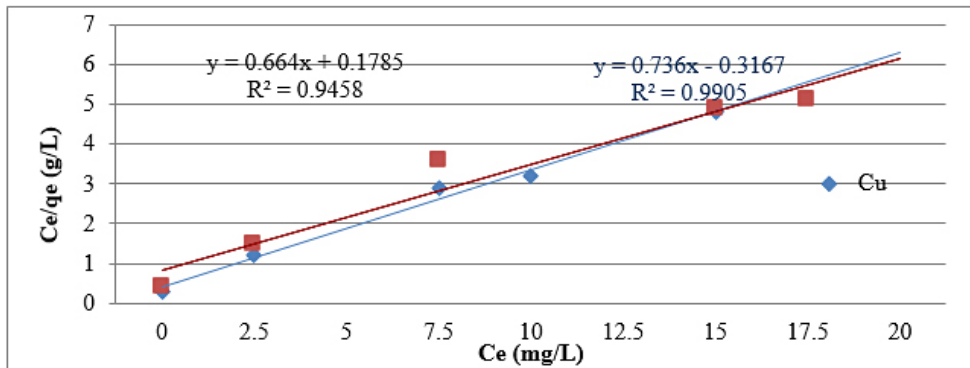


Fig. 10: Langmuir model line of  $C_e/q_e$  vs  $C_e$  of the metal-ions on the CCH

Table 3 presents the Langmuir model constants is  $K_L$  and  $q_{max}$ , alongside the  $R^2$  values. The correlation coefficients ( $R^2$  values) exceeding 0.90 for entirely metal content represents that the Langmuir model effectively interprets the adsorption data. The Langmuir-constants,  $q_{max}$ , and  $K_L$  were resultant after the linear lines' plot slope and interrupt. Typically,  $q_{max}$ , representing the Langmuir capacity for monolayer coverage, is utilized to compare adsorbents' efficiencies with other materials tested as biosorbents for metal ions in chemical literature. Table 4 summarizes the heavy metal adsorption capacities (mg/g) of various common adsorbents, including bamboo dust and its activated form used in this study. Differences in adsorption capacities among adsorbents may stem from the types of functional groups on biosorbents, influencing their affinity for metal ions, as well as variations in particle size affecting surface area and porosity. In our study, bamboo dust adsorbed Cu and Zn at rates of 4.42 and 4.16 mg/L respectively, while bamboo-based activated charcoal adsorbed them at rates of 4.67 and 4.57 mg/L correspondingly, as shown in Table 4 alongside other adsorbents from literature. This indicates bamboo wastes effectiveness as adsorbents for removing these metal-ions from aqueous solutions. Further, our work showed that Cu was more proficiently adsorbed than Zn on both surfaces.

The Langmuir adsorption coefficient ( $K_L$ ) for the metal ions exhibited high values, indicating a strong affinity of the adsorbents for these ions and suggesting a sharp onset of the isotherm for metal ion adsorption. The fundamental characteristics of Langmuir isotherms are further elucidated through

a dimensionless parameter known as the separation factor  $R_L$ , defined as:

$$R_L = \frac{1}{(1 + K_L C_0)} \quad \dots(6)$$

Here,  $C_0$  represents the initial metal content, and  $K_L$  denotes the Langmuir constant. As elaborated by McKay *et al.*<sup>43</sup> and Horsfall *et al.*,<sup>44</sup> the  $R_L$  is shows the form of the isotherm:  $R > 1$  signifies an unfavourable isotherm,  $R_L = 1$  suggests a linear model isotherm,  $R_L = 0$  indicates an irreversible model isotherm, and  $0 < R_L < 1$  implies a favourable model isotherm. The  $R_L$  values attained for both metal-ions, Cu and Zn, on the two adsorbents at an initial content of 100 mg/L are all  $< 1$ . This indicated that the isotherm was favorable under the settings of our work and suggests that the adsorbents might serve as effective alternate for the extraction of metal contents.

**Equilibrium Freundlich Isotherm**

The Freundlich-model isotherm was adopted to appraise the affinity of adsorbates, such as metal contents, for adsorbents. This model gives insight into the intensity of adsorption interactions.<sup>45</sup> The linearized representation of the Freundlich model is articulated as:

$$\ln q_e = \ln k_F + \frac{1}{n} \ln C_e \quad \dots(7)$$

The parameters  $K_F$  and  $1/n$  in the Freundlich equation characterize the adsorption process in terms of its intensity and capacity, respectively. Figure 11 and Figure 12 illustrate linear plots of  $\ln k_F$  versus  $\ln C_e$

adhering to the Freundlich model equation. These plots allow for the determination of  $K_F$  and  $1/n$  from the intercept and slope, which are then tabulated in Table 5. The  $K_F$  values indicate the ease with which adsorption occurs, facilitating the separation of heavy metals from aqueous. Meanwhile, the exponent,  $n$ , elucidates the distribution of bonded metal contents on the adsorbent surfaces, thereby providing insight into the favorability and capacity

of the adsorption process. Anusiem *et al.*<sup>45</sup> noted that values of  $n$  falling from 1-10 signify favorable adsorption settings. In this study, the exponent ranged from 2.382 to 2.798 across all cases, indicating advantageous adsorption for the system. The high  $R^2$  values attained signify that the isotherm accurately interprets the adsorption behaviour of the metal ions.<sup>48</sup>

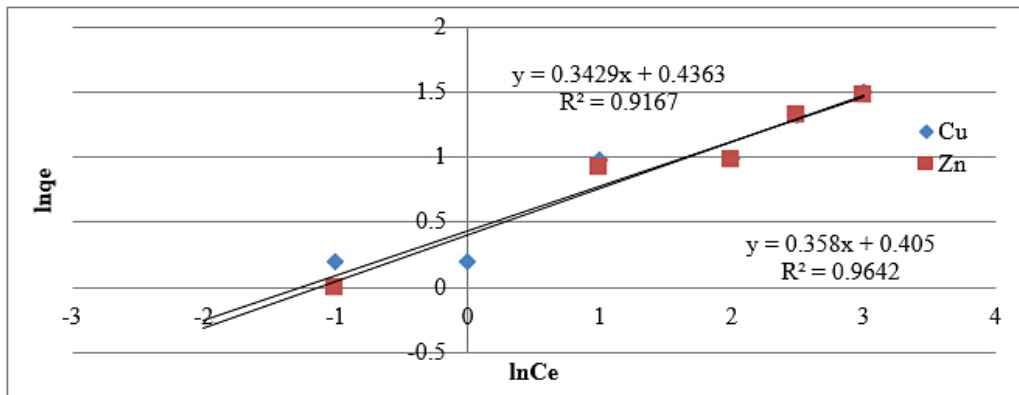


Fig. 11: Freundlich isotherm line of  $\ln q_e$  vs  $\ln C_e$  of the metal-ions onto CH

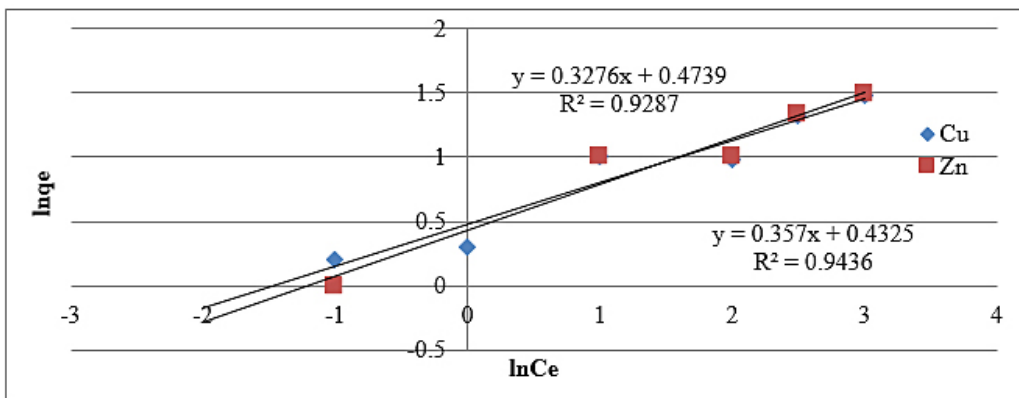


Fig. 12: Freundlich isotherm line of  $\ln q_e$  vs  $\ln C_e$  of the metal-ions onto CCHH

**Analysis of the Coefficient using Isotherm Models**

The coefficient of estimation ( $R^2$ ) serves as a vital tool in regression analysis, elucidating the interplay between variables pivotal for assessing kinetic and thermodynamic parameters in adsorption processes. In the current study, various isotherm models such as Langmuir and Freundlich were employed to scrutinize data. These models are represented by equations

akin to  $y = mx + c$  ( $m$  = slope and  $c$  = intercept), underscoring the requisite linear relationship between  $y$  and  $x$  for predictive utility.<sup>47-50</sup>

$R^2$  signifies the extent to which variations in  $y$  values are explicable through the linear relationship with  $x$ , delineated by the regression line. A value of  $R^2$  at zero suggests non-correlation between the variable value of one represents perfect significant

relation. Hence,  $R^2$  values within the range of zero to one are instrumental in evaluating experimental data. The coefficients of determination for the four aforementioned isotherm models Langmuir and Freundlich were compared, with  $R^2$  values approaching unity indicative of superior fitting models. In this investigation, the Freundlich isotherm emerged as the most apt descriptor for adsorption-phenomenon of the two metal contents, closely tracked by the Langmuir isotherm.

### Conclusion

Current work confirmed the efficacy of CH and CCH as adsorbents for extracting Cu and Zn ions in aqueous. The investigation focused on the encouragement of pH and metal content on the adsorption process. Results indicated a proportional enhance in adsorption capacity with rising metal contents, with the more adsorption capacity of Cu and Zn occurring at pH 6.0. Analyzing the experimental values adopting Langmuir and Freundlich isotherm models revealed high  $R^2$  values, with the Freundlich model exhibiting the best fit compared to Langmuir isotherm. CH exhibited superior affinity for Cu and Zn, and both adsorbents demonstrated better removal capabilities for the metal ions compared to CCH. The adsorption mechanism was identified as physisorption, supported by the outward energy of adsorption calculated from these models. In conclusion, CH and CCH show promise as effective adsorbents for eliminating Cu and Zn in aqueous solutions, suggesting potential applications in industrial effluent treatment.

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### Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript. The authors have not declared any conflict of interests.

### Data Availability Statement

The research data associated with a paper is available, and under what conditions the data can be accessed.

### Ethics Approval Statement

Study doesn't involve an experiment on humans and animals.

### Authors' Contribution

Corresponding author conceived of the presented idea and developed the theory and performed the computations. First author verified the analytical methods and encouraged to investigate and supervised the findings of this work. Both authors discussed the results and contributed to the final manuscript.

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