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Using Susuh Kura (Sulcospira *testudinaria*) Shell to Mitigate Heavy Metal Pollution in Batanghari River

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Abstract. The Batanghari River, as the primary water source for the Jambi City Water Utility (PDAM), has been subjected to pollution caused by anthropogenic activities, particularly those stemming from industrial, agricultural, and domestic sectors. Concentrations of heavy metals such as mercury (Hg), cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn) have been detected at levels exceeding the limits established by Government Regulation No. 22 of 2021. This research aimed to mitigate the presence of heavy metals in the Batanghari River through adsorption techniques utilizing Susuh kura snail shells as a natural adsorbent. The characterization of the adsorbent was conducted using Scanning Electron Microscopy (SEM) to analyze its morphology and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to assess the heavy metal content in the river water. The snail shells were treated under varying thermal conditions: uncalcined, and calcined at 500 °C and 700 °C. The results indicated that calcium oxide (CaO) derived from shells calcined at 500 °C exhibited the highest adsorption efficiency, achieving up to 80% reduction in heavy metal concentrations. These findings suggest that waste snail shells possess significant potential as a low-cost, eco-friendly natural adsorbent for addressing heavy metal contamination in aquatic environments, offering a sustainable solution for water treatment.

Keywords: Adsorption, Snail Shell, ICP-MS, Heavy Metals, Batanghari River, SEM

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Introduction

The Batanghari River in Jambi City serves as one of the primary water sources for the local water utility company (PDAM). With a flow rate of approximately 3,500 m^3/second and six intake points, the river supports a total water demand of around 1,250 L/second. However, the river is heavily burdened by waste discharges from various human activities including agriculture, industry, and domestic households which significantly impact its water quality [1]. Previous studies have revealed that the Batanghari River contains elevated levels of heavy metals such as cadmium (Cd), copper (Cu), and mercury (Hg) which exceed the quality standards set by regulatory authorities [2]. The deteriorating water quality of the Batanghari River represents a critical environmental issue that demands immediate and effective solutions. Among the most harmful pollutants are heavy metals such as mercury (Hg), cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn). These contaminants are classified as hazardous and toxic waste (B3), thereby requiring systematic mitigation efforts to prevent further environmental degradation [3]. Previous studies have demonstrated that various techniques can be employed to reduce heavy metal concentrations in water, including precipitation, membrane filtration, ion exchange, ion addition, conventional filtration, ultrafiltration, electrodialysis, and adsorption [4].

Adsorption is considered an alternative method that can be applied to reduce heavy metal contamination in water. This technique is regarded as more economical due to its simple design and operation, low initial cost, high removal efficiency, selectivity toward specific ions, and the availability of abundant and low-cost adsorbent materials [5]. Nurfauziah et al. (2021) investigated the removal of copper (Cu) ions using an adsorption method and reported a removal efficiency of 96.29% within 25 minutes [6]. This research explores the potential application of Susuh kura (Sulcospira testudinaria) snail shells as an adsorbent for the removal of heavy metals from the Batanghari River. It aims to provide new insights into the utilization of snail shell waste as an effective and low-cost adsorbent, while also offering a promising strategy for addressing aquatic pollution. As such, the findings may contribute to the advancement of more efficient and environmentally sustainable adsorption technologies for mitigating heavy metal contamination in the Batanghari River [7]. The Susuh kura snail is recognized as a traditional delicacy in Merangin Regency (Bangko), as reported by Herlianto (2021) [8]. However, the utilization of Susuh kura shells in Indonesia remains limited. In some regions, the shells are used as food ingredients or as raw materials for handicrafts. Nevertheless, a significant amount of shell waste is still discarded into the environment, particularly around local eateries and food stalls [9]. These shells were selected due to their abundance as a solid waste material in the Jambi region and their lack of optimal utilization. Previous research has demonstrated that calcium oxide (CaO) can serve as an effective adsorbent for reducing heavy metal concentrations in water. The Susuh kura shells are rich in calcium carbonate ($CaCO_3$), which can be thermally converted into CaO through a calcination process. This research is expected to benefit both the local community and government by offering a practical solution to water pollution challenges. Moreover, it seeks to provide valuable insights into the potential of snail shell waste as a natural adsorbent for heavy metal adsorption. Ultimately, the research presents a promising alternative for addressing heavy metal pollution in the Batanghari River.

Experimental

The Materials. Laboratory equipment used during chemical preparation and processes included 100 mL graduated cylinders, 250 mL beakers, Erlenmeyer flasks, glass stirring rods, watch glasses, funnels, spatulas, and a magnetic stirrer. The primary material used in this study was the shell of the Susuh kura snail (Sulcospira testudinaria). The snail samples were obtained from a previous study conducted by the research team [10]. All samples were collected and stored following standardized procedures to ensure their quality and suitability for subsequent analysis, which served as the adsorbent following preparation and calcination. River water samples from the Batanghari served as the main subject of analysis, with heavy metal content measured both before and after the adsorption process. The instruments employed in this research included a Scanning Electron Microscope (SEM) to analyze the surface morphology of the adsorbent and Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) to determine the concentration of heavy metals in water from the Batanghari River.

Research Procedure. The overall research procedure can be outlined in three interrelated main stages: characterization of the adsorbent, characterization of Batanghari River water samples prior to adsorption, and the adsorption process itself. The following provides a systematic explanation of this workflow:

Characterization of Susuh Kura Shell Based Adsorbent. The initial stage of the research began with the characterization of the adsorbent derived from susuh kura snail shells. The adsorbent was first subjected to calcination to enhance its surface activity. Subsequently, Scanning Electron Microscopy (SEM) was employed to examine the surface morphology of the adsorbent, including its porosity and potential active sites. These characteristics are crucial for understanding the material's adsorption capacity toward heavy metals in water.

Characterization of Batanghari River Water Before Adsorption. Following the adsorbent characterization, the Batanghari River water samples were analyzed prior to the adsorption treatment. Sampling locations were determined based on spatial analysis and previous studies. The concentrations of heavy metals, specifically iron (Fe) and mercury (Hg), in the water were then analyzed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). This stage was intended to establish the baseline levels of heavy metal contamination in the river water.

Adsorption Process of Batanghari River Water. At this stage, the calcined adsorbent was added to 100 mL of Batanghari River water sample. The mixture was stirred using a magnetic stirrer at a speed of 100 rpm for 30 minutes. The primary objective of this procedure was to maximize the interaction between the heavy metal ions in the water and the active surface of the adsorbent. Upon completion of the adsorption process, the water samples were re-analyzed using ICP-MS to assess the changes in heavy metal concentrations. Overall, this research workflow was designed to evaluate the effectiveness of a locally sourced biomaterial-based adsorbent in reducing heavy metal content in contaminated water, specifically in the Batanghari River. Each stage is systematically interconnected and collectively supports the comprehensive objectives of the research. Next stage adsorption efficiency (% R) was evaluated to determine the effectiveness of the calcined Susuh kura snail shell adsorbent in removing metal ions [10]. The percentage removal (%R) was calculated using the following equation

$$\%R = \frac{C1-C2}{C1} \times 100\% \quad (1)$$

where C1 is the initial concentration of the metal ion (mg/L), and C2 is the equilibrium (or final) concentration after the adsorption process (mg/L).

Result and Discussion

Scanning Electron Microscope (SEM) Analysis of Susuh Kura Shell. SEM provides fundamental information about the microstructural transformation of Susuh kura shell during calcination at high resolution. Efficiency of metal adsorption is strongly influenced by the surface characteristics of the adsorben. The objective of this analysis is to identify differences in particle size and shape [11]. SEM characterization of Susuh kura shell was conducted at magnifications of 3,000x, 8,000x, and 12,000x. The morphological structure of the material was analyzed through SEM imaging. Figure 1 presents the SEM results of the uncalcined sample at 3,000x magnification, revealing that the particles have irregular shapes and uneven surfaces. The particles tend to be relatively large and agglomerated, indicating that the natural shell structure remains intact and has not undergone decomposition.

At magnifications of 8,000x and 12,000x, the surface morphology appears more detailed. However, the surface still appears rough and compact, with no visible open pores. This suggests that the crystalline structure has not fully formed due to the absence of high-temperature treatment. The morphology of the Sulcospira testudinaria shell calcined at 500 °C, as shown in Figure 2 at 3,000x magnification, reveals initial changes in surface structure compared to the uncalcined sample. Cracks and small pores begin to form, indicating partial structural transformation. However, the particles still tend to agglomerate, suggesting that 500 °C is not yet optimal for breaking down larger structures into nanoparticles. At higher magnifications (8,000x and 12,000x), the particle surface starts to exhibit a porous structure, although the distribution remains uneven. This indicates that the calcination process has initiated the decomposition of carbonate compounds, but has not yet fully developed the ideal nanoporous morphology. At a calcination temperature of 700 °C, the SEM results shown in Figure 3 at 3,000x magnification indicate that the particle sur-

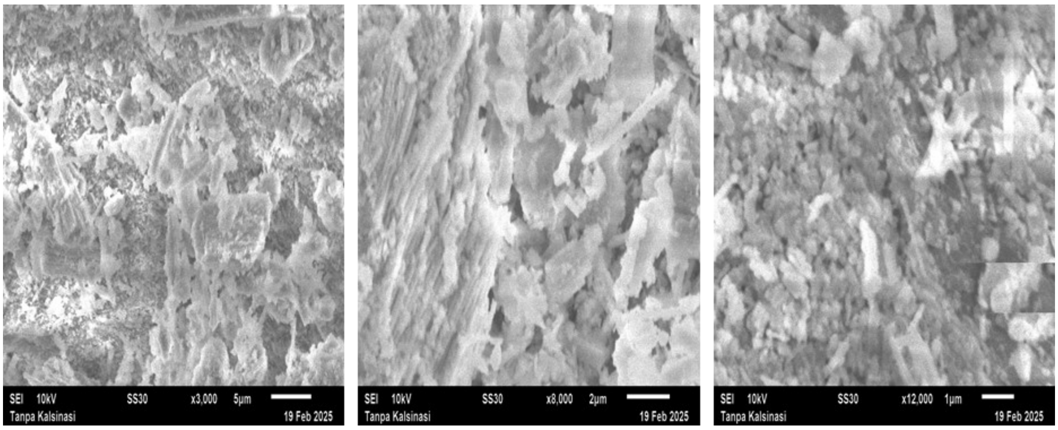

Figure 1. Surface morphology of Susuh kura shell (*sulcospira testudinaria*) without calcination at magnifications of (a) 3,000x, (b) 8,000x, and (c) 12,000x

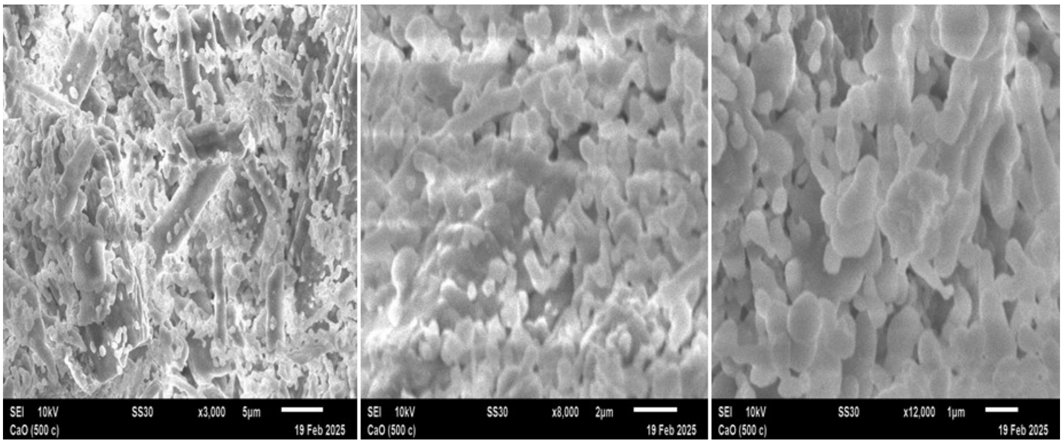

Figure 2. Surface morphology of Susuh kura shell (*Sulcospira testudinaria*) calcined at 500 °C at magnifications of (a) 3,000x, (b) 8,000x, and (c) 12,000x

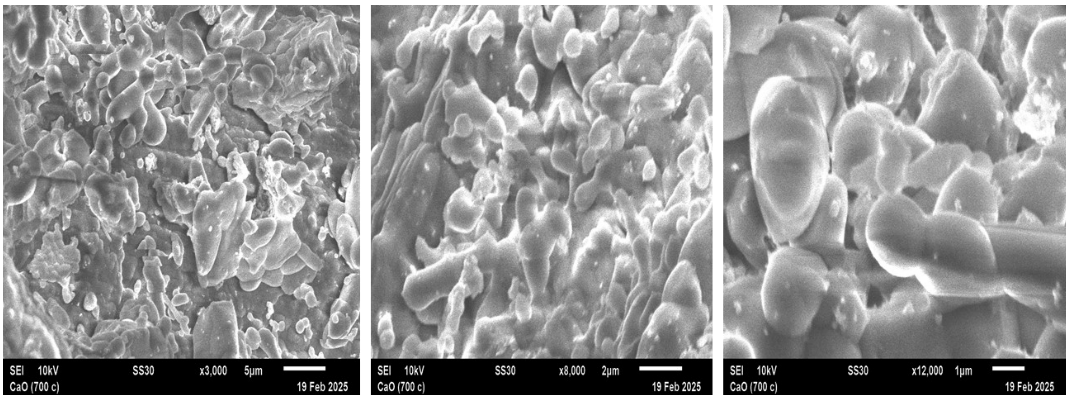

Figure 3. Surface morphology of Susuh kura shell (*Sulcospira testudinaria*) calcined at 700 °C at magnifications of (a) 3,000x, (b) 8,000x, and (c) 12,000x

faces appear more porous and rougher compared to those treated at 500 °C. The particle structure becomes more dispersed and less agglomerated, suggesting that the decomposition of $CaCO_3$ into CaO is proceeding more effectively.

At higher magnifications of 8,000x and 12,000x, the surface morphology appears more uniform than at the lower temperature. Clearly defined pores and a more irregular surface are visible, indicating that at 700 °C, crystalline structures begin to form and particle sizes approach the nanoscale. These observations are consistent with the findings of Arrizal [12], which reported that high-temperature calcination facilitates the transformation of $CaCO_3$ into CaO with a more uniform and porous morphology.

ICP-MS Analysis Results of Batanghari River Water Treated with CaO. ICP-MS (Inductively Cou-

Table 1. Results of Metal Adsorption Tests on Batanghari River Water

Metal	Batanghari River water (mg/L)	Uncalcined Adsorbent (mg/L)	Calcined Adsorbent (mg/L)	
			(500 °C)	(700 °C)
Al	0,0545	0,0413	0,0088	0,0102
As	0,0424	0,0387	0,0122	0,0135
Ca	2,01	1,87	1,00	1,04
Cd	0,0617	0,0555	0,0324	0,0345
Co	0,0415	0,0310	0,0152	0,0163
Cr	0,0345	0,0302	0,0102	0,0110
Cu	0,0441	0,0367	0,0106	0,0130
Fe	0,0576	0,0352	0,0211	0,0235
Hg	0,0120	0,100	0,0080	0,0085
K	1,67	1,34	0,55	0,62
Mg	2,28	1,98	1,02	1,10
Mn	0,0314	0,0288	0,0078	0,0084
Na	1,76	1,12	0,35	0,42
Ni	0,0342	0,0288	0,0076	0,0090
Pb	0,0222	0,0176	0,0055	0,067
Sn	0,0251	0,0187	0,0092	0,0100
Zn	0,0565	0,0415	0,0122	0,034

pled Plasma-Mass Spectrometry) is one of the analytical instruments used to identify and quantify heavy metals in environmental samples [13]. In this research, ICP-MS was employed to assess the effectiveness of CaO adsorbent in removing heavy metals from water through the adsorption process. The results of heavy metal analysis using CaO as the adsorbent are presented in Table 1 and Table 2.

Table 1 show of laboratory testing of Batanghari River water samples contamination with various types of heavy metals at varying concentrations. The concentration of dissolved metals in the river water ranged from 0.0120 mg/L (Hg) to 2.28 mg/L (Mg), with metals such as Calcium (Ca), Potassium (K), Sodium (Na), and Magnesium (Mg) showing relatively high concentrations. The presence of these metals in the river water indicates anthropogenic activities such as domestic, agricultural, and industrial waste disposal that contribute significantly to the pollution of the Batanghari River [14].

Based on Table 1, toxic heavy metals such as Pb (0.0222 mg/L), Cd (0.0617 mg/L), Cr (0.0345 mg/L), Co (0.0415 mg/L), and Hg (0.0120 mg/L) were detected in the water samples, indicating potential health risks to the aquatic ecosystem and humans who use the river water. Several heavy metal concentrations in the Batanghari River water exceeded the maximum allowable limits set by Government Regulation No. 22 of 2021, such as zinc (Zn) at 0.05 mg/L, mercury (Hg) at 0.001 mg/L, calcium (Ca) at 0.02 mg/L, and magnesium (Mg) in the range of 0.02–2 mg/L. However, some metals were still within the acceptable thresholds, including aluminum (Al) at 0.2 mg/L, arsenic (As) at 0.05 mg/L, sodium (Na) at 200 mg/L, cadmium (Cd) at 0.01 mg/L, copper (Cu) at 0.02 mg/L, chromium (Cr) at 0.05 mg/L, cobalt (Co) at 0.2 mg/L, iron (Fe) at 0.3 mg/L, manganese (Mn) at 0.1 mg/L, nickel (Ni) at 0.05 mg/L, lead (Pb) at 0.03 mg/L, and tin (Sn) at 2 mg/L. Meanwhile, potassium (K), with a standard range of 0.1–2 mg/L, remained within the permissible limits. Therefore, based on the reference values for water quality standards outlined in Government Regulation No. 22 of 2021, it can be concluded that the Batanghari River is contaminated with heavy metals. This conclusion aligns with previous findings [14] which categorized the Batanghari River as severely polluted by heavy metals such as Hg, Cd, Pb, Fe, and Mn.

The calcination process significantly increases the adsorption capacity of Susuh Kura Shell. After adsorption with the uncalcined adsorbent, show decrease in metal concentrations across most elements. This suggests that the adsorbent possesses active surface sites capable of binding both cationic and anionic species. However, a more significant reduction was observed when the adsorbent was calcined, particularly at 500 °C and 700 °C. Calcination enhanced the porosity and surface reactivity of the adsorbent, improving its metal removal efficiency [10]. Across all evaluated metal contaminants, calcium (Ca), magnesium (Mg), and sodium (Na) exhibited the highest initial concentrations and were reduced from 2.01 mg/L to 1.00 mg/L (Ca), 2.28 mg/L to 1.10 mg/L (Mg) and 1.76 mg/L to 0.42 mg/L (Na) for calcination at 500°C. Similarly, transition metals such as Fe, Cu and Zn showed significant decreases after calcination at 700°C, with Fe dropping from 0.0576 mg/L to 0.0235 mg/L, Cu from 0.0441 mg/L to 0.0160 mg/L, and Zn from 0.0565 mg/L to 0.034 mg/L. Table 2 presents the data on metals adsorption performance from equations 1 using a adsorbent Susuh kura shell.

Table 2 presents the adsorption efficiency (%R) of metals ions using Susuh kura shells as a biosorbent under three conditions: untreated, calcined at 500 °C, and calcined at 700 °C. In general, thermal activation significantly improved adsorption performance. The adsorbent calcined at 500 °C exhibited the highest efficiency for most metals, such as As (71.22%), Cr (71.18%), K (67.06%), and Mn (75.15%). This suggests that 500 °C is an optimal activation temperature that enhances the porosity and surface area of the material without compromising its functional structure [17]. However, at 700 °C, certain metals such as Hg and Cr showed a decrease in adsorption efficiency. For instance, Hg dropped from 33.33% (500 °C) to 29.16%, and Cr from 71.18% to 68.92%. This decline may be attributed to pore collapse or sintering effects at high temperatures, which can reduce the number of active sites available for adsorption [19]. Overall, the findings demonstrate that thermal treatment at 500 °C is the most effective condition for enhancing the adsorption capacity of Sulcospira testudinaria shells, in agreement with previous studies by Wiyantoko et al. (2022) that highlight the importance of temperature optimization in biosorbent activation [18].

In general, CaO calcined at 500 °C produced the most effective adsorption results for nearly all heavy metals tested, indicating that this temperature represents the optimal condition for CaO adsorbent activation. Based on the measured concentrations of metals in the Batanghari River, it can be concluded that the river contains a variety of major and transition metals. The major metals identified include Al, As, Ca, K, Mg, Na, Sn, and Zn. Meanwhile, the detected transition metals comprise Cd, Co, Cu, Cr, Fe, Hg, Mn, Ni, Pb, and Se. The adsorption profile of major metals in the Batanghari River is presented in Figure 4.

Figure 4 show the concentrations of several major metals (Al, As, Co, Ca, K, Na, Sn, and Zn) present in Batanghari River water. Among these, three alkali and alkaline earth metals calcium (Ca), potassium (K), and sodium (Na) were found to be the most dominant. A substantial reduction in the concentrations of these metals was observed following the adsorption process, particularly when using adsorbents calcined at 500 °C. This trend indicates a high affinity between the metal ions and the thermally activated adsorbent surface, which enhances the material's adsorption capacity for alkali ions. These results are consistent with findings reported by Zhang et al. (2019) [16]. The concentration of Ca^{2+} ions in the untreated sample reached the highest level (~2.1 mg/L). However, after treatment with

Table 2. Result of metals adsorption performance using Susuh kura shell

Metal	Metal efficiency (%)	Metal efficiency 500 ^{0}C (%)	Metal efficiency 700 ^{0}C (%)
Cd	10,04	47,48	44,08
Ca	6,96	50,24	48,25
As	10,84	71,22	68,16
Al	24,22	65,50	81,28
Co	25,30	63,37	60,72
Cr	14,68	71,18	68,92
Cu	16,78	75,96	70,52
Hg	16,66	33,33	29,16
K	19,76	67,06	62,87
Mg	13,15	67,06	51,75
Mn	8,28	75,15	73,24
Na	36,36	80,11	76,13
Ni	15,78	77,77	73,68
Pb	20,72	75,22	69,81
Sn	25,49	63,34	60,15
Zn	26,54	78,40	74,33
Fe	37,91	62,78	58,55

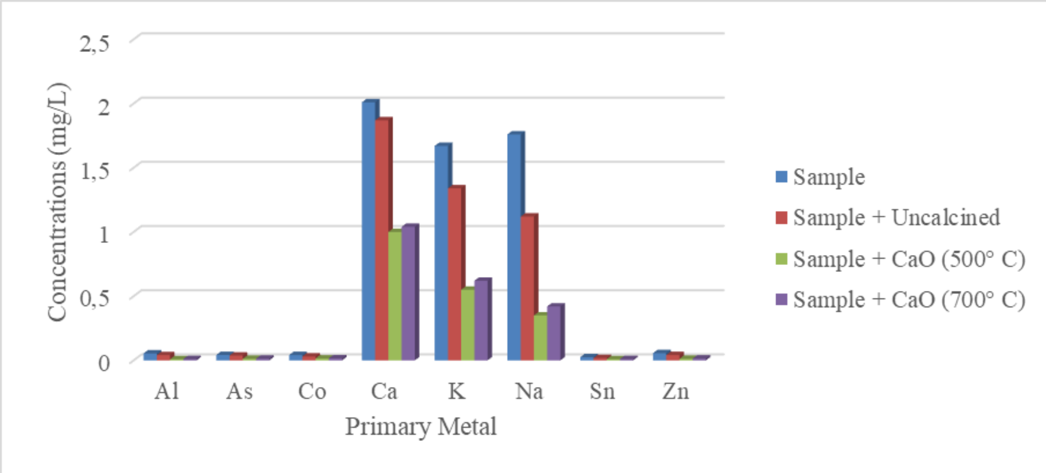

Figure 4. Adsorption of Primary Metals in Batanghari River Water

the calcined adsorbent at 500 °C, a more pronounced decrease in concentration was observed compared to the 700 °C treatment, with levels dropping to 1.0 mg/L and 0.9 mg/L, respectively. Similar patterns were observed for K^+ and Na^+ ions: the concentration of K^+ decreased from ~1.7 mg/L to 0.5 mg/L, while Na^+ levels declined from ~1.8 mg/L to ~0.3 mg/L following treatment with the 500 °C adsorbent. These findings suggest that 500 °C is the optimal calcination temperature for enhancing the adsorption of these metal ions from Batanghari River water. Wiyantoko et al. (2022) previously reported that although calcination improves the oxide structure of adsorbents, adsorption efficiency does not always increase linearly with temperature [17].

The optimal adsorption performance depends on specific parameters such as surface chemistry and pH. Similarly, Ulfiati et al. (2023) noted that while calcination temperatures above the metakaolin formation point (~509 °C) can increase surface area, excessive temperatures or prolonged calcination can cause structural damage due to sintering, leading to a loss of microporosity and a decline in adsorption activity [18]. For other metal elements such as Al, As, Co, Sn, and Zn, the final concentrations showed minimal variation across all treatments and remained below 0.1 mg/L. This limited change is likely due to the already low initial concentrations of these elements in the river water samples. The concentration of zinc (Zn) in the Batanghari River water was measured at 0.0565 mg/L, exceeding the maximum allowable limit [19]. These levels refer to the water quality standards established under Government Regulation No. 22 of 2021 concerning water quality criteria in Indonesia. Batanghari River water also contains several transition metals, as illustrated in the Figure 5.

Figure 5 show the Batanghari River has been contaminated by several transition metals, including Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb. The concentrations of these metals refer to the standards outlined in Government Regulation No. 22 of 2021

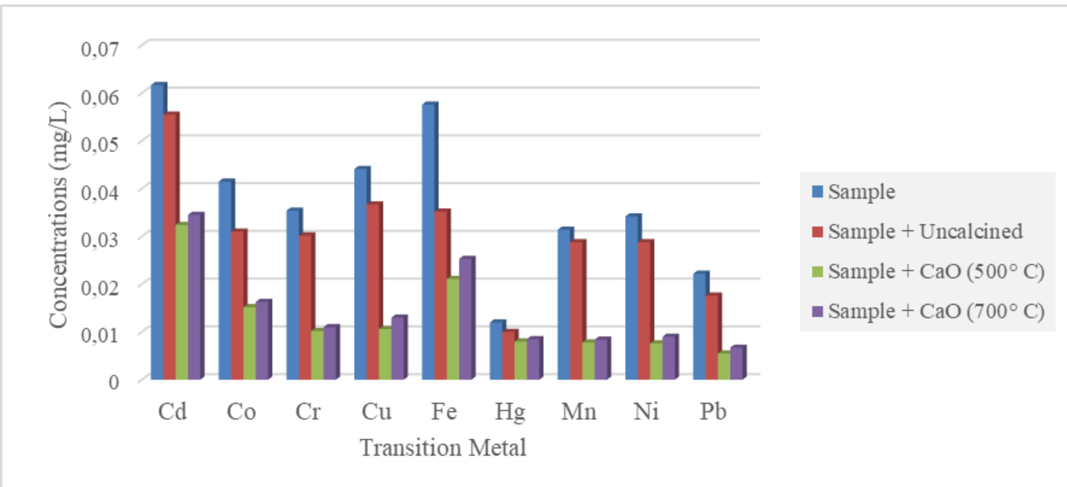

Figure 5. Adsorption of Transition Metals in Batanghari River

concerning environmental management. Fe and Cd metals are the main contributors to metal pollution in Batanghari River water, with the highest concentration compared to other metals. Based on these data, it was found that the addition of CaO as an adsorbent significantly reduced the metal concentration compared to the initial sample, and thermal activation at 500°C resulted in the highest adsorption efficiency for almost all metal elements. When CaO was calcined at 500° C, its effectiveness increased significantly. Cd, Fe, and Cu metals showed the greatest decrease in concentration after treatment with the addition of calcined CaO, from >0.05 mg/L in the initial sample to <0.02 mg/L. This effect indicates that the surface of the calcined CaO provides more reactive active sites to bind metal ions through precipitation, surface complexation, or ion exchange mechanisms. Rahmawati et al (2020) reported that calcined CaO from shell waste significantly reduced Pb and Cd levels through precipitation and surface reactions [20]. Other metals such as Co, Cr, Hg, Mn, Ni, and Pb also experienced a gradual decrease in concentration from uncalcined to modified conditions [21]. The best results were obtained by adding activated CaO to the sample at 500°C. These results align with previous research showing that calcining CaO at moderate temperatures (between 500–600°C) is optimal for producing an effective adsorbent without damaging its internal structure. If the calcination temperature used is too high, it will cause pore blockage or damage to the active groups during the adsorption process [22], [18]. This temperature likely optimizes the adsorption properties of CaO, thereby enhancing its efficiency in binding and removing heavy metal contaminants from the water [23].

Conclusion

Based on the results of this research, it can be concluded that the shell of Susuh kura snail can be utilized as an effective adsorbent due to its ability to remove metal contaminants from the Batanghari River water. Scanning Electron Microscope (SEM) analysis revealed that calcination at 500 °C and 700 °C induced significant morphological changes in the shell structure. At both temperatures, pore formation was observed on the surface of the adsorbent, which enhanced its capacity for heavy metal adsorption. CaO calcined at 500 °C demonstrated the highest adsorption efficiency for heavy metals, including Cr (71.18%), Cu (75.96%), Pb (75.22%), and Zn (78.40%). A decline in adsorption efficiency was observed at 700 °C, likely due to structural transformations that reduced the material's adsorptive capacity.

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