Natural Bioadsorbent of Kepok Banana Peel in Reducing Mercury (Hg) Heavy Metal in Langkapa River, Bombana

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ABSTRACT

Gold mining in Bombana Regency, Southeast Sulawesi, requires environmental monitoring in the Langkapa River cause to potential mercury (Hg) exposure. Initial measurements showed an Hg concentration of 0.8106 µg/L, which is close to the maximum limit of 1 µg/L (equivalent to 0.001 mg/L) permitted by the Indonesian Minister of Health Regulation Number 2 of 2023, thus requiring preventive measures. This study evaluated the effectiveness of kepok banana (*Musa paradisiaca L.*) peel waste as a natural bioadsorbent to reduce Hg in Langkapa River water using a batch system adsorption method. This is an experimental study using variations in adsorbent mass (0.5; 1; 5; and 10 grams) and contact time (30, 60, 90, 120, 150, and 180 minutes) at 100 rpm. Equilibrium was modeled using Langmuir and Freundlich isotherms, while kinetics were evaluated through pseudo-first-order and pseudo-second-order models. The bioadsorbent achieved high Hg removal efficiency of 98.9% at 10 grams mass and 99.6% at 180 minutes contact time, thus reducing the Hg concentration to 0.0086 µg/L and 0.0031 µg/L, respectively, far below the quality standard threshold. The data best fit the Freundlich isotherm ($R^2 = 0.9051$) and the pseudo-second-order kinetic model ($R^2 = 1$). This indicates a multilayer chemisorption process on a heterogeneous surface. These results indicate that kepok banana peel waste offers an adsorption solution as an economical, effective, and sustainable natural bioadsorbent to address the risk of mercury accumulation in waters.

Introduction

Bombana Regency is a strategic region in Southeast Sulawesi Province, with a land area of approximately 3,316.16 km^2 (331,616 ha) and a sea area of approximately 11,837.31 km^2. Its geographical characteristics include being surrounded by mountains, forests, and rice fields, making the agricultural sector the primary source of livelihood for the local community. In addition to agriculture, marine resources are also an important economic resource for the community, given the Regency's geographical location, surrounded by mountains and vast oceans. However, the community's economic development changed after the discovery of gold nuggets in the Tahi Ite River, Bombana Regency, in early 2008. This discovery encouraged the community and the Regional Government to make the mining sector a primary source of livelihood and regional income [1]. On the one hand, the existence of this industry has had a positive impact on investment, infrastructure development, and increased regional income and the welfare of the surrounding community [1].

However, on the other hand, this activity also causes environmental pollution due to uncontrolled gold mining practices. Extracting gold from rocks is generally done using hazardous chemicals, including mercury (Hg). Mining waste is often dumped directly into rivers without prior treatment. As a result of this waste disposal over the years, the river and well water around the mine site, which was once clear, has become cloudy, foul-smelling, and foamy, making it unsuitable for daily use or drinking by residents. The highly toxic and persistent nature of mercury means that its negative impacts on water sources remain in the environment, even after mining activities cease [2].

The Langkapa River serves as the primary raw water source for the Bombana Regency Regional Drinking Water Company (PDAM), supplying approximately 155 liters/second to local residents [3]. An initial quality assessment of the Langkapa River indicated a Hg concentration of 0.8106 µg/L, close to the

[1] Fikriansyah, "Kabupaten Bombana : Dari Pemekaran Wilayah Hingga Dinamika Pertambangan Emas, 2003-2021."
[1] Suwantara and Jaya, "Strategi Petani Di Sekitar Tambang Emas (Kajian Antropologi Ekologi Di Desa Kalaero Kecamatan Lantari Jaya."
[2] Ido et al., "Impact Of Gold Mining On Water Quality In Bombana Regency Southeast Sulawesi Province, Indonesia."
[3] Natsir, Sudia, and Ramadhan, "Analisis Indeks Pencamaran Air Di Sungai Langkapa Kabupaten Bombana, Analysis Of Water Pollution Index In The Langkap River Bombana Regency."

maximum permissible limit of 1 µg/L (or equivalent to 0.001 mg/L) stipulated in Minister of Health Regulation (Permenkes) No. 2 of 2023. Therefore, it is possible that Hg levels have accumulated throughout the water, spreading to various watercourses, resulting in the water still containing Hg. Mercury is a toxic heavy metal. Mercury reacts in the body by inhibiting enzyme activity, disrupting the body's metabolic processes. The use of mercury in gold mining can potentially lead to mercury pollution [4].

The most efficient method for treating water pollution is adsorption, which involves adding adsorbents to the water. Adsorption is a technique for reducing pollutant content in water by absorbing atoms, ions, or molecules in solution onto the surface of an absorbent. The adsorbent is the substance that absorbs, while the adsorbate is the substance that is absorbed [5]. Currently, biomass-based adsorbents are a good solution for natural water purification because they contain biodegradable organic materials, are environmentally friendly, and relatively safe for human life. One alternative technology that can be used for natural water purification is the use of banana peels [6].

Banana peels are biomass waste containing several organic compounds such as cellulose, hemicellulose, lignin, and pectin. These compounds contain various functional groups, such as hydroxyl (–OH), carboxyl (–COOH), and amine (–NH2), which can interact with metal ions and pollutants in water through ion exchange, complexation, and electrostatic bonding. The presence of these functional groups in the biomass cell walls allows turbidity-causing particles to be electrostatically attracted to the surface of the banana peel pores, which act as adsorbents [6].

Based on data from the Central Statistics Agency (BPS) of Bombana Regency in 2025, banana production in this region increased from 17,064 quintals in 2021 to 24,802 quintals by 2025 [7]. Therefore, utilizing banana peel waste as a natural adsorbent has significant potential for sustainable development. Considering that the people of Bombana Regency only use the fruit as raw material for business products, such as banana dempo, banana jam, and other food preparations that use bananas as raw materials, while the peel only becomes organic waste that is simply thrown away, so it only becomes waste and a source of environmental pollution.

Based on research by Musafira et al. (2015) shows that the bioadsorbent of kepok banana peel can achieve mercury removal of 99.89% with an adsorption capacity of 29.96 mg/g at an initial Hg concentration of 60 ppm [8]. So, this study was conducted aimed to test the effectiveness of kepok banana peel as a bioadsorbent in reducing mercury metal in the Langkapa River which is suspected of containing Hg even though it is still in low concentrations. In addition, the results of the adsorption method to model the adsorption equilibrium using Langmuir and Freundlich isotherms, and to determine the adsorption kinetics using pseudo-first-order and pseudo-second-order models. The results were compared with the water quality standards of Permenkes No. 2 of 2023 to assess the feasibility of this approach for drinking water purification.

Methods

Sampling Location

The sampling location was Watuwalangkari Village, Rarowatu District, Bombana Regency, Southeast Sulawesi Province.

Sample Collection and Preparation

Sampling in this study was carried out by taking water samples from the Langkapa River in Watuwalangkari Village, Rarowatu District. This coordinate point serves as a permanent reference for regular monitoring of the quality of raw water sources in the Langkapa River. The reservoir water sample was taken at the Langkapa Intake at the coordinate point -4.756769°S - 121.989278°E. Water sampling in this study referred to SNI 06-2412-1991. The waste water sample from the sampling site is collected in two Liter polyethylene bottles and stored in a refrigerator at 4°C.

[4] Musafira et al., "The Adsorption of Mercury Metal Ion Using Kepok Banana's Peel Waste (Musa Paradisiaca Formatypica) Charcoal."
[5] Rifai, Azhar, and Rositawati, "Pemanfaatan Limbah Kulit Pisang Sebagai Adsorben Alami Untuk Menurunkan Kadar Logam Berat Pb(II) Dalam Air."
[6] Maliandra, Shatriadi, and Zairinayati, "Efektivitas Kulit Pisang Dalam Menurunkan Kekeruhan Dan Kadar Besi (Fe) Pada Air Sumur Gali."
[7] Bombana, *Kabupaten Bombana Dalam Angka Tahun 2025*.
[8] Musafira, Pratiwi, and Mirzan, "Pemanfaatan Limbah Kulit Pisang Kepok (Musa Paradisiaca Formatypica) Sebagai Biosorben Logam Merkuri (Hg)."

Batch Adsorption Experiments

Batch adsorption experiments were conducted in two series: (1) variation of adsorbent mass and (2) variation of contact time. For the mass variation study, 100 mL of raw Langkapa River water was treated with 0.5, 1, 5, and 10 gram of bioadsorben at a stirring speed of 100 rpm for 60 minutes at room temperature. For the contact time study, 10 gram of bioadsorben was contacted with 100 mL of water sample for 30, 60, 90, 120, 150, and 180 minutes at 100 rpm.

Mercury concentrations were measured before and after adsorption using Atomic Absorption Spectrophotometry (AAS) at a wavelength of 253.7 nm. Adsorption efficiency (%) and adsorption capacity qe (µg/g) were calculated using the standard formulas:

$$\textit{Adsorption Efficiency}\ (\%) = \frac{C_0 - C_e}{C_0}\ x\ 100\ \% \quad \text{.....(1)}$$

$$\textit{Adsorption Capacity}\ (Qe) = \frac{C_0 - C_e}{m}\ V \quad \text{.....(2)}$$

where C_0 is the initial concentration (µg/L), Ce is the equilibrium concentration (µg/L), V is the volume of solution (L), and m is the mass of adsorbent (g).

Adsorption Isotherm and Kinetics Modeling

Adsorption equilibrium data were fitted to Langmuir and Freundlich isotherm models. The Langmuir model assumes monolayer adsorption on a homogeneous surface, while the Freundlich model describes multilayer adsorption on a heterogeneous surface. The best-fit model was selected based on the highest coefficient of determination (R^2). Adsorption kinetics were modeled using pseudo first order and pseudo second order equations, with model selection based on R^2 values closest to unity.

Results and Discussions

Effect of Adsorbent Mass on Mercury Removal

The influence of kepok banana peel bioadsorben mass on Hg removal from Langkapa River water is presented in Figures 1.

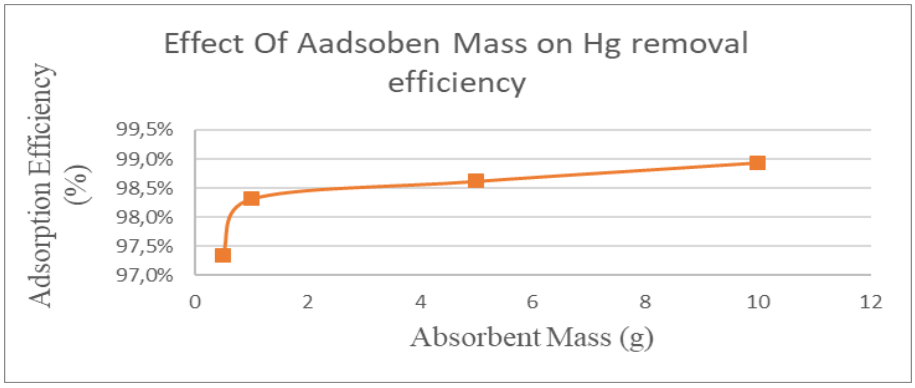


Figure 1. Effect Of Adsorbent Mass On Hg Adsorption Efficiency (%)

The results of the study showed that the kepok banana peel bioadsorbent was able to reduce mercury levels from Langkapa River water with all variations of adsorbent mass. The research results obtained The final Hg concentration was successfully reduced from the initial value of 0.8106 µg/L to a range of 0.0216 - 0.0086 µg/L, which is far below the quality standard of Permenkes No. 2 of 2023 of 1 µg/L (equivalent to 0.001 mg/L).

Based on Figure 1 in the graph The Hg removal efficiency achieved was very high, namely a mass of 0.5 grams reached 97.3%; a mass of 1 gram reached 98.3%; a mass of 5 grams reached 98.6%; and a mass of 10 grams reached 98.9%. This is in accordance with Lestari's research (2010) that the more adsorbent used, the more active sites (C=O and -OH) contained in the adsorbent that can absorb metals. These active sites are used for chemical adsorption (chemisorption) by forming metal complexes with the active sites on the adsorbent surface. Furthermore, increasing the biosorbent dose also triggers the diffusion of metal ions toward the adsorbent surface, thus optimizing the interaction between the metal ions and the active sites [9]

[9] Lestari, "Pengaruh Berat Dan Waktu Kontak Untuk Adsorpsi Timbal(II) Oleh Adsorben Dari Kulit Batang Jambu Biji (Psidium Guava L.)."

According to Yulis and Sari (2022), an increase in the amount of adsorbent means there are more active components, such as hydroxyl and carboxyl groups, that can bind mercury, thus increasing the absorption percentage [10].

Adsorption capacity is measured to determine the amount of adsorbate that can accumulate on the adsorbent surfaca. The adsorption process is directly proportional to the adsorption capacity. Therefore, if the adsorption process is running optimally, the adsorption capacity will also be the same. Adsorption capacity is obtained by calculating the initial Hg content (Co) minus the final Hg content (Ce), then dividing by the adsorbent mass, and then multiplying by the adsorbate volume (L). Figure 2 shows the results of calculating the Hg metal adsorption capacity based on variations in mass.

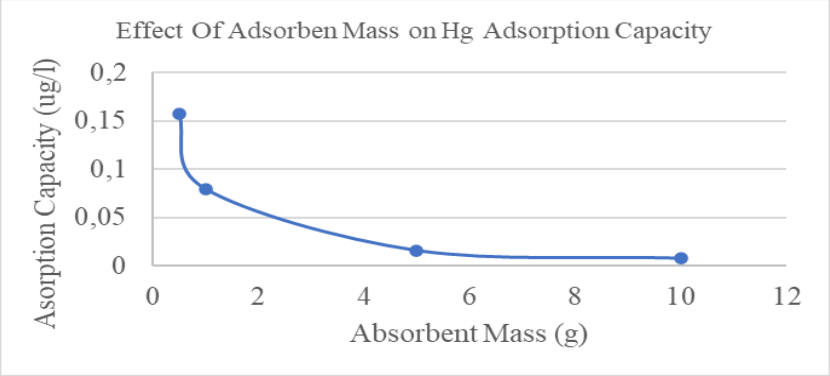


Figure 2. Effect Of Adsorbent Mass On Hg Adsorption Efficiency (µg/L)

Based on the graph, the adsorption capacity for mercury (Hg) decreased with increasing adsorbent mass. The highest adsorption capacity was achieved at a minimum adsorbent mass of 0.5 grams, at 0.1578 µg/g. This value continued to decrease at 1 gram of adsorbent mass to 0.07969 µg/g, then to 0.015988 µg/g at 5 grams, and finally reached its lowest value at a maximum adsorbent mass of 10 grams, at 0.00802 µg/g.

This occurs because increasing the amount of adsorbent means more active sites are available, but not all of them are occupied by the adsorbate. This condition causes a decrease in the adsorption capacity because, as is known, the adsorption capacity is the ability of the adsorbate to accumulate on the adsorbent surface. Therefore, this decrease in adsorption capacity is due to not all active sites on the adsorbent being completely occupied by the adsorbate [11].

Effect of Contact Time on Mercury Removal

The effect of contact time (30–180 minutes) on Hg removal using 10 gram of kepok banana peel bioadsorben is summarized in Figure 3.

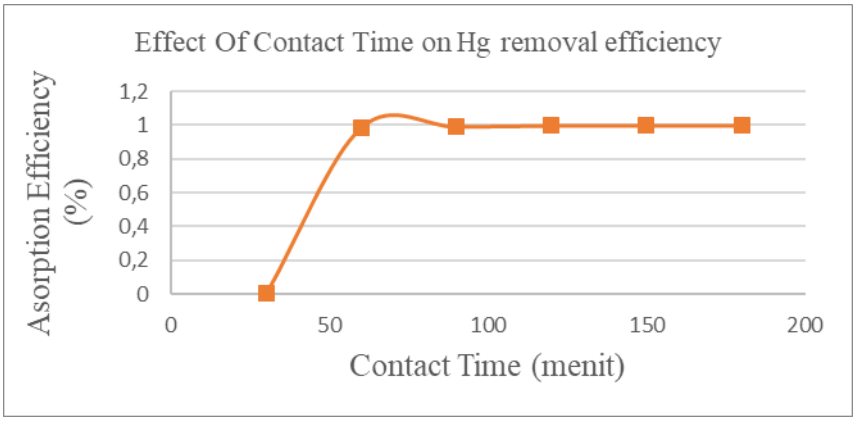


Figure 3. Effect Of Contact Time On Hg Adsorption Efficiency (%)

Based on research results, the Kepok banana peel bioadsorbent demonstrated a fairly good ability to reduce mercury (Hg) concentrations in raw water from the Langkapa River with increasing contact time. The

[10] Yulis and Sari, "Kepok Banana Peels as Biosorbent for Mercury Sorption from Artificial Wastewater."
[11] Putri and Wahida, "Pemanfataan Kulit Pisang Kepok (Musa Paradisiaca L.) Sebagai Adsorben Untuk Menurunkan Kadar COD (Chemical Oxygen Demand) Pada Air Limbah Laundry."

results observed in mercury (Hg) adsorption showed a very high adsorption efficiency of 98.7% from the 30th minute, and continued to increase slowly to 99.6% at the 150th and 180th minutes, with final concentrations of 0.0032 and 0.0031 µg/L, respectively [13]. These results align with research by Musafira et al. (2015) who used kepok banana peel as a biosorbent for mercury metal. Musafira et al. (2015) reported that the equilibrium time was reached at 30 minutes with an adsorption percentage of 99.89% and an absorption capacity of 29.96 mg/g at an initial mercury concentration of 60 ppm [9].

Adsorption Isotherm

To understand the adsorption equilibrium mechanism, Langmuir and Freundlich isotherm models were applied to the mercury adsorption data. The data used to determine this adsorption isotherm is data from an adsorbent mass variation experiment, which can be seen in the Figure 4. showing the Freundlich isotherm plot for Hg adsorption from Kepok banana peel bioadsorbent.

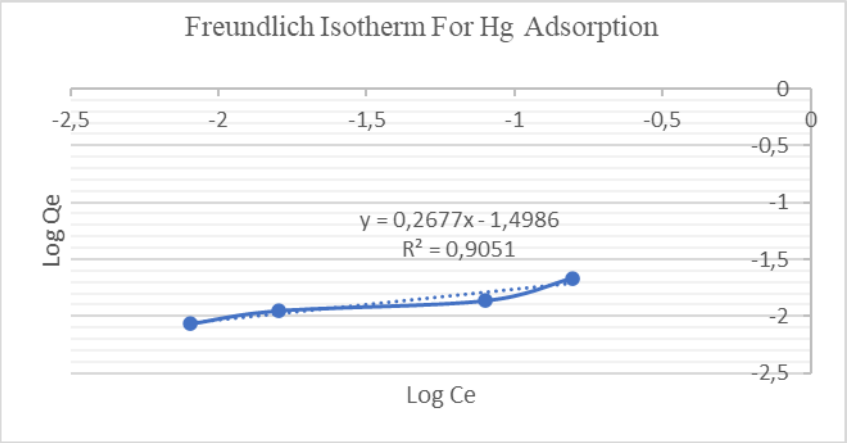


Figure 4. Ferundlich isotherm for Hg Adsorption

Based on graphic Figures 4, The Freundlich isotherm model provided a better fit for Hg adsorption data (R^2 = 0.9051) compared to the Langmuir model (R^2 = 0.6913). The Freundlich model assumes the adsorption The adsorption mechanism is physical adsorption, which assumes that the interaction occurs by Hg metal entering the pores of the adsorbent through electrostatic interactions or interacting with weak bonding forces, such as van der Waals bonds [12]. According to [13] an n value in the Freundlich isotherm within the range of 1-10 is considered favorable for the adsorption process. Furthermore, a 1/n value, which indicates adsorption intensity, of less than 1 also indicates favorable adsorbent conditions for use as an adsorbent due to the strong interaction between the adsorbate and adsorbent, preventing the adsorbate from easily detaching from the adsorbent surface. The n value in this study was 3.736, with a 1/n value of 0.000267, indicating that the use of kepok banana peel as an adsorbent in the Hg metal adsorption process was mutually favorable (unfavorable). This illustrates the strong interaction between the Hg metal adsorbate and the banana peel bioadsorbent, preventing the adsorbate from easily separating from the adsorbent surface, resulting in an optimal adsorption process. The linearity parameter data from the two isotherm models for each heavy metal are summarized in full in Table 1.

Table 1. Langmuir and Freundlich Isotherm Parameters for Adsorption of Heavy Metals Hg on Kepok Banana Peel Bioadsorbent

Logam Berat	Langmuir			Freundlich		
	Q_{max} (mg/g)	K_L (L/mg)	R^2	N	K_f min^{-1}	R^2
Hg	0.6961	-0.0216	0.6913	3.736	3,17 x 10^{-2}	0.9051

[9] Musafira, Pratiwi, and Mirzan, "Pemanfaatan Limbah Kulit Pisang Kepok (Musa Paradisiaca Formatypica) Sebagai Biosorben Logam Merkuri (Hg)."
[12] Rokhati et al., "PMANFAATAN TONGKOL JAGUNG SEBAGAI ADSORBEN LIMBAH LOGAM BERAT."
[13] Atkins, Paula, and Keeler, *Physical Chemistry*.

Based on Table 1, the Langmuir affinity constant is negative (KL = −0.0216 L/mg) indicating that the Langmuir model is not a valid representation of this adsorption system, which further confirms that adsorption does not follow the assumption of a homogeneous monolayer surface inherent in the Langmuir model.

Adsorption Kinetics

Adsorption kinetics is used to determine the rate of adsorption by an adsorbent on an adsorbate and is influenced by time. The contact time required to reach adsorption equilibrium is used as a measure of the adsorption rate [14]. Adsorption kinetics is one of the characteristics that determine the efficiency of the adsorption process. The adsorption kinetics models used in this study are pseudo-first-order and pseudo-second-order adsorption kinetics.

The pseudo-first-order kinetics model describes a reversible equilibrium between the liquid phase (adsorbate) and the solid phase (adsorbent). The pseudo-second-order kinetics model explains that the rate-limiting stage of adsorption is considered chemical adsorption through various mechanisms such as electrostatic interactions, complex formation, or chelate formation. Pseudo-first-order kinetics are constructed by plotting t vs. log (qe - qt). t is time and log (qe - qt) is the logarithm of the reduction of the adsorbed substance at the optimum time with the adsorbed substance at a certain time, while the pseudo second order kinetics is made by plotting t Vs t/qt. t is time and t/qt is time per amount of substance adsorbed at a certain time. The results of pseudo second order kinetics that describe Hg Metal can be seen in Figure 5.

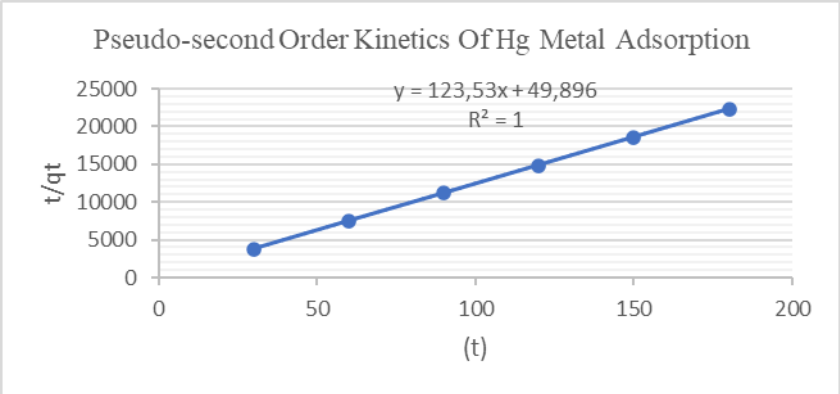


Figure 5. Pseudo-second Order Kinetics Of Hg Metal Adsorption

Based on graphic Figures 5, The pseudo-second-order kinetic model provided an excellent fit for Hg adsorption data with R^2 = 1.000, significantly outperforming the pseudo-first-order model (R^2 = 0.6488). Pseudo second order assumes that the adsorption rate of the solute is proportional to the available sites on the adsorbent used, in addition the reaction rate depends on the amount of solute [15]. The data for determining the adsorption kinetics are shown in Table 2.

Table 2. Comparison of Data for Determining Pseudo-First Order and Pseudo-Second Order Adsorption Kinetics

Logam Berat	Orde 1			Orde 2		
	R	Qe (µg/g)	K_1 (meni^{-1})	R	Qe (µg/g)	K_2 (menit^{-1})
Hg	0.6488	0.001979	−0,0372	1	0,008193	298,59

Based on Table 2, The pseudo-second-order rate constant k_2 = 298.59 mg·µg^{-1}·min^{-1} for Hg further confirms the rapid and strong chemical interaction between mercury ions and the bioadsorben active sites. The calculated equilibrium adsorption capacity (qe = 0.008193 µg/g) is consistent with the experimental

[14] Haryanto et al., "Kajian Kemampuan Adsorpsi Batang Jagung (Zea Mays.) Terhadap Ion Logam Kadmium (Cd2+)."
[15] William et al., "Modelling of Adsorption Kinetic Processes—Errors, Theory and Application. Advanced Sorption Process Applications."

values, validating the applicability of this model. These results are consistent with the findings of [9] and [11] who also reported pseudo-second-order kinetics for mercury adsorption on banana peel-derived materials.

Conclusions

This study shows that kepok banana peel waste (*Musa paradisiaca L.*) is an effective natural bioadsorbent for removing heavy metal mercury (Hg) in the Langkapa River, Bombana Regency, Southeast Sulawesi. The results showed that kepok banana peel bioadsorbent achieved a high Hg removal efficiency of 97.3%–98.9% with increasing adsorbent mass from 0.5 to 10 grams, thus meeting the standards of the Minister of Health Regulation No. 2 of 2023, which is ≤1 µg/L. The maximum efficiency of 98.9% was achieved with an adsorbent mass of 10 grams. The effect of contact time confirmed that adsorption equilibrium was reached at 150 minutes, with an Hg removal efficiency of 99.6% and a final concentration of 0.0031 µg/L. The adsorption equilibrium was best described by the Freundlich isotherm model (R^2 = 0.9051), which showed multilayer adsorption on the heterogeneous bioadsorbent surface with a dominant physisorption mechanism. The adsorption kinetics followed a pseudo-second-order model (R^2 = 1.000), which confirmed that the rate-limiting step was chemisorption through complexation between Hg ions and active functional groups (-OH, -COOH) on the banana peel surface. The kepok banana peel bioadsorbent showed that the decrease in Hg concentration followed a pseudo-second-order adsorption kinetics (R^2 = 1) and offered a cost-effective, locally available, and environmentally sustainable solution for heavy metal removal from river water. Further research is recommended to test the effectiveness of kepok banana peel bioadsorbent and other local biomass either without activation or through appropriate physical or chemical activation for raw water samples from the Langkapa River and water samples in the Regency area that have been contaminated with heavy metals in water.

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Author Contributions

“Conceptualization, R and AA; methodology, R, RR, AA; software, R, RR, AA; validation, RR and AA; formal analysis, R; investigation, R; resources, R, RR, AA; data curation, R; writing—original draft, R; writing—review and editing, RR and AA; visualization, R; supervision, RR and AA; project administration, R; funding acquisition, -.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Fikriansyah, D., (2023). *“Kabupaten Bombana : Dari Pemekaran Wilayah Hingga Dinamika Pertambangan Emas, 2003-2021.”* Prograsm Studi Magister Sejarah Fakultas Ilmu Budaya Universitas Hasanuddin. Please use this link https://repository.unhas.ac.id/id/eprint/30290/2/F052202002_tesis_07-06-2023%201-2.pdf

[2] Suwantara, G P, and S A Jaya. “Strategi Petani Di Sekitar Tambang Emas (Kajian Antropologi Ekologi Di Desa Kalaero Kecamatan Lantari Jaya.” *Jurnal Kerabat Antropologi* 6, No. 1 (2022): 342–52. Please use this link http://journal.fib.uho.ac.id/index.php/kabantiantropologi/article/view/1645

[9] Musafira, Pratiwi, and Mirzan, “Pemanfaatan Limbah Kulit Pisang Kepok (Musa Paradisiaca Formatypica) Sebagai Biosorben Logam Merkuri (Hg).”

[11] Yulis and Sari, “Kepok Banana Peels as Biosorbent for Mercury Sorption from Artificial Wastewater.”

[3] Ido, I, Sawaludin, Mukhtar, and A Lio. "Impact Of Gold Mining On Water Quality In Bombana Regency Southeast Sulawesi Province, Indonesia." *Advances In Environmental And Geological Science And Engineering*, 2019. Please use this link https://www.researchgate.net/publication/334372856_Impact_of_Gold_Mining_on_Water_Quality_in_Bombana_Regency_Southeast_Sulawesi_Province_Indonesia

[4] Natsir, A, L B Sudia, and L O A Ramadhan. "Analisis Indeks Pencamaran Air Di Sungai Langkapa Kabupaten Bombana, Analysis Of Water Pollution Index In The Langkap River Bombana Regency." *Jurnal Perencanaan Wilayah*, 2021. DOI:10.33772/jpw.v6i1.16347

[5] Musafira, Dzulkifli, Fardinah, and L Qadrini. "The Adsorption of Mercury Metal Ion Using Kepok Banana's Peel Waste (*Musa Paradisiaca Formatypica*) Charcoal." *KOVALEN: Jurnal Riset Kimia* 6, no. 1 (2020): 39–44. DOI:10.22487/kovalen.2020.v6.i1.15043

[6] Rifai, M, H Azhar, and L Rositawati. "Pemanfaatan Limbah Kulit Pisang Sebagai Adsorben Alami Untuk Menurunkan Kadar Logam Berat Pb(II) Dalam Air." *Pure Chemistry Research* 1, no. 1 (2022). https://doi.org/10.70716/purechem.v1i1.267

[7] Maliandra, S M R, H Shatriadi, and Zairinayati. "Efektivitas Kulit Pisang Dalam Menurunkan Kekeruhan Dan Kadar Besi (Fe) Pada Air Sumur Gali." *Masker Medika* 4, no. 2 (2014): 371–81. Please use this link http://jmm.ikestmp.ac.id/index.php/maskermedika/article/view/126.

[8] Bombana, B P S Kabupaten. *Kabupaten Bombana Dalam Angka Tahun 2025*, (2025). 2528-374X. Please use this link https://bombanakab.bps.go.id/id/publication/2025/02/28/cd8270134f7270f621fdc5c2/kabupaten-bombana-dalam-angka-2025.html

[9] Musafira, W Pratiwi, and M Mirzan. "Pemanfaatan Limbah Kulit Pisang Kepok (Musa Paradisiaca Formatypica) Sebagai Biosorben Logam Merkuri (Hg)." *Natural Science: Journal of Science and Technology*, 2015. Volume 4 Number 2. Please use this link https://garuda.kemdiktisaintek.go.id/documents/detail/1324555

[10] Lestari, S. "Pengaruh Berat Dan Waktu Kontak Untuk Adsorpsi Timbal(II) Oleh Adsorben Dari Kulit Batang Jambu Biji (Psidium Guava L.)." *J. Kim. Mulawarman* 8, no. 1 (2010): 7–10. Please use this link https://jrk.fmipa.unand.ac.id/index.php/jrk/article/view/596

[11] Yulis, P A R, and Y Sari. "Kepok Banana Peels as Biosorbent for Mercury Sorption from Artificial Wastewater." *JKPK (Jurnal Kimia Dan Pendidikan Kimia)* 7, no. 1 (2022):64-75. DOI:10.20961/jkpk.v7i1.56353

[12] Putri, D P, and S A Wahida. "Pemanfataan Kulit Pisang Kepok (Musa Paradisiaca L.) Sebagai Adsorben Untuk Menurunkan Kadar COD (Chemical Oxygen Demand) Pada Air Limbah Laundry." *Jurnal Informasi, Sains Dan Teknologi* 5, no. 02 (2022): 71–77. https://doi.org/10.55606/isaintek.v5i02.66.

[13] Rokhati, N, A Prasetyaningrum, N Hamada, A L C Utomo, H B Kurniawan, and I H Nugroho. "Pemanfaatan Tongkol Jagung Sebagai Adsorben Limbah Logam Berat." *Inovasi Teknik Kimia* 6, no. 2 (2021): 89–94. DOI:10.31942/inteka.v6i2.5508

[14] Atkins, P, J De Paula, and J Keeler. *Physical Chemistry*. 11th ed. Oxford University Press, n.d.

[15] Haryanto, B, P Firmanto, H Herman, and R Rifai. "Kajian Kemampuan Adsorpsi Batang Jagung (Zea Mays.) Terhadap Ion Logam Kadmium (Cd2+)." *Pertanian Andalas* 20, no. 1 (2014): 59–68. https://doi.org/10.30598/MJOCEVOL9ISS1PP9-17

[16] William, K G, S Emik, A Öngen, and Kurtulu. "Modelling of Adsorption Kinetic Processes—Errors, Theory and Application. Advanced Sorption Process Applications," n.d. https://doi.org/10.5772/intechopen.80495.