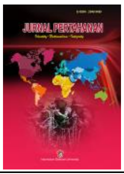

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Integrating Heavy Metal Adsorption on Organic Waste Materials into Defense and Security Studies: A Sustainable Approach

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Abstract

This study aims to examine the plausible fusion of heavy metal adsorption through lignin derived from organic waste materials into the realm of defense and safety studies. This study underscores the imperative nature of addressing heavy metal pollution within defense operations and environmental conservation. It proposes utilizing lignin, derived from organic waste materials, as a pivotal solution to combat heavy metal contamination. By synthesizing insights from existing literature, this research delves into lignin's potential as a highly effective adsorbent tailored for the defense sector. The study illuminates lignin's versatility in interacting with heavy metals through multifaceted adsorption mechanisms, offering a sustainable strategy to mitigate environmental harm while fortifying national resilience. Derived from diverse biomass sources, including peanut shells, cocoa pod shells, coconut shells, rice husks, and empty oil palm fruit bunches, lignin exhibits promising adsorption capacities attributed to its ample surface area and diverse functional groups. Emphasizing a holistic perspective, this research advocates for an integrated approach that harnesses lignin's robust adsorption capabilities to meet the specific demands of defense and security, envisioning a future that is both secure and sustainable. This is attributed to the inherent properties of lignin, such as its abundant surface area and diverse functional groups. The lignin derived from these biomasses offers a versatile and effective solution, showcasing high adsorption potential due to its ability to accommodate various heavy metal ions and contribute to sustainable environmental remediation practices. By synergizing lignin's robust adsorption attributes with the requisites of defense and security, this research advocates for a comprehensive approach, fostering a vision of a secure and sustainable future.

INTRODUCTION

Over the past decade, the interrelated concerns of environmental sustainability and national security have gained prominence on a global scale. The rapid escalation of industrial activities and population growth has led to a significant upsurge in the release of heavy metals into the environment. Defined by their density exceeding 5 g/cm^3, heavy metals pose considerable threats to the natural world due to their inherent toxicity (Supriyantini & Soenardjo, 2016). The multifaceted problem of heavy metal pollution encompasses diverse metal ion types and properties (Juharna, Widowati, & Endrawati, 2022), including prominent examples such as lead (Pb), mercury (Hg), cadmium (Cd), iron (Fe), and copper (Cu) (Mayangsari, Apriyani, & Veptiyan, 2019).

Concurrently, the domain of national resilience and security grapples with increasingly intricate challenges, encompassing threats to critical infrastructure and military operations stemming from heavy metal contamination (McKay et al., 2021). Possessing inherently detrimental chemical properties, heavy metals can wreak havoc when they accumulate excessively in the environment or living organisms (Tarekegn, Salilih, & Ishetu, 2020). Such accumulations within the human body can result in nervous system disorders reproductive complications, organ damage, and even cancer risks (Anisyah & Joko, 2016). As heavy metal-laden pollution enters river systems, it dissolves into water and settles in sediment (Proshad et al., 2021), with the potential to amplify over time based on prevailing water conditions (Wulan, Thamrin, & Amin, 2018). Notably, heavy metals tend to amass within the tissues of living organisms (Bhat, Hassan, & Majid, 2019), progressively accumulating through the consumption of contaminated food and water, consequently inflicting enduring harm (Utami, Rismawati, & Sapanli, 2018).

Meanwhile, within the purview of defense and security studies, the imperative to mitigate vulnerabilities arising from heavy metal contamination of defense infrastructure and systems stands as an integral facet of comprehensive national defense strategies. The presence of heavy metals in defense environments can disrupt operational readiness, impair equipment functionality, and curtail tactical capabilities (McKay et al., 2021). Consequently, the convergence of environmental sustainability principles with defense and security studies is assuming growing significance, holding the potential to forge a harmonious and mutually advantageous sustainable approach.

Lignin stands out among various promising adsorbents, such as zeolite, diatom, clay, humic acid, and silica, due to several distinct advantages. Firstly, lignin is derived from plant biomass, particularly wood, making it a renewable and abundant resource (Nawawi, Fatrawana, & Syafii, 2021). This contrasts with certain synthetic adsorbents that rely on non-renewable materials. Additionally, lignin's biodegradability is a noteworthy feature, as it can be naturally broken down by microorganisms, contributing to its environmentally friendly profile (Hermansson, Janssen, & Svanström, 2019). The diverse functional groups present in lignin, including hydroxyl, methoxyl, and phenolic groups (Berghuis, Novianti, & Ratri, 2023), enhance its versatility in adsorption applications, allowing it to effectively capture a wide range of pollutants. Moreover, lignin can be chemically modified to further improve its adsorption properties, providing a customizable and adaptable solution for various environmental and industrial challenges. These features collectively position lignin as a sustainable and effective adsorbent in comparison to other alternatives (Sternberg, Sequert, & Pilla, 2020).

This research aims to bridge this knowledge gap by examining the plausible fusion of heavy metal adsorption through lignin derived from organic waste materials into the realm of defense and safety studies. By dissecting adsorption mechanisms, material characteristics, and prospective applications, this study endeavors to yield valuable insights conducive to devising sustainable strategies to confront existing environmental and safety challenges. The primary objective of this research is to explore and evaluate the potential of various organic waste materials, including peanut shell waste, cocoa pod shell waste, coconut shell waste, rice husk waste, and empty oil palm fruit bunch waste, as effective adsorbents for heavy metals. The study aims to investigate the adsorption capacities of these waste materials for specific heavy metals such as lead (Pb), copper (Cu), iron (Fe), cadmium (Cd), and mercury (Hg). Additionally, the research seeks to address the implications of utilizing these organic waste adsorbents in the context of defense and security, focusing on environmental sustainability and responsible waste management within the defense sector

METHODS

1. Selection of Organic Waste Materials
   The selection process involved identifying organic waste materials with potential adsorption capabilities for heavy metals. Criteria such as abundance, accessibility, and prior research demonstrating adsorption properties were considered.
2. Heavy Metal Adsorption Experiments
   Laboratory experiments were conducted to assess the adsorption capacities of the selected organic waste materials for specific heavy metals. The process involved preparing adsorbents, creating metal solutions of varying concentrations, and subjecting the adsorbents to adsorption tests.
3. Defense and Security Considerations
   To address the defense and security implications, a comprehensive literature review was undertaken to understand the potential environmental impact of defense activities on heavy metal pollution. Key areas of focus included military training, equipment usage, defense industry practices, and the role of the Indonesian National Armed Forces (TNI) in environmental conservation.
4. Environmental Impact Assessment
   An environmental impact assessment was conducted to quantify the contribution of defense-related heavy metal pollution. The assessment included evaluating potential pathways of metal release, assessing environmental risks, and identifying vulnerable ecosystems.
5. Mitigation and Best Practices Proposal
   Based on the findings, mitigation strategies and best practices were proposed for minimizing heavy metal pollution within the defense sector. These recommendations aimed to enhance environmental responsibility, sustainable waste management, and the adoption of eco-friendly practices in defense operations.
6. Data Analysis
   Data obtained from laboratory experiments, literature reviews, and environmental impact assessments were analyzed using statistical methods and qualitative analysis techniques. The goal was to draw meaningful conclusions regarding the effectiveness of organic waste materials as heavy metal adsorbents and to provide actionable insights for defense-related environmental management.
7. Sustainable Approach Integration
   The research integrated a sustainable approach by emphasizing the importance of aligning environmental solutions with security imperatives. This involved exploring how the use of organic waste materials as adsorbents aligns with broader

sustainability goals and contributes to national security through responsible defense practices.

It is essential to acknowledge certain limitations in this study, including variations in organic waste composition, potential regional differences in heavy metal concentrations, and the complexity of defense-related environmental impacts. The research, while comprehensive, may not cover all possible scenarios, and further investigations are encouraged to build upon the findings presented in this study.

In this study, the systematic literature review method approach was adopted as a foundation for collecting, evaluating, and synthesizing information related to the integration of heavy metal adsorption using lignin from organic waste materials into defense and safety studies. The systematic literature review method allows for a structured and holistic analysis of the relevant literature, enabling conclusions based on a comprehensive evidence base. The initial stage involves establishing inclusion and exclusion criteria that ensure the inclusion of only high-quality and relevant literature by the research focus. Through systematic searches, using relevant keywords and terms, appropriate literature is found from a variety of academic sources.

After the literature selection, an in-depth analysis was conducted to explore information about the research methods used in the selected studies, the main findings produced, as well as the potential implications of the integration of heavy metal adsorption using lignin in defense and security contexts. It is from here that information from various literature sources is synthesized, and general trends, differences, and similarities are identified and interpreted within the research framework. Drawing conclusions based on literature analysis provides a comprehensive summary, details potential implications, and underscores directions for further research or practical application in this continuous integration. With this approach, this research is expected to provide in-depth insight into the potential and constraints involved in applying this sustainable approach in the realm of defense and security.

RESULT AND DISCUSSION

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Peanut Shell Waste as Lead (Pb) Heavy Metal Adsorbent

Peanut shells can act as adsorbents because they contain cellulose, lignin, and hemicellulose components that have hydroxyl and carboxyl functional groups found in their cell walls (Islam et al., 2019). Organic compounds such as lignin and cellulose in peanut shells can interact with heavy metals, making them effective in the adsorption process. When peanut shells are activated with acids or bases, their structure and surface properties change, increasing their adsorption capacity. In addition, its large pores and wide surface make it possible to accommodate heavy metal ions (Oktasari, 2018).

The adsorption capacity of Pb(II) ions is different in peanut shells activated with acids or bases. Activation with acid can increase the adsorption capacity because it can increase the number of acid groups on the surface of the peanut shell. Activation with bases can increase adsorption capacity because it can increase the number of base groups on the surface of peanut shells. In addition, activation with bases can also increase the surface area and porosity of peanut shells. Therefore, activation with acids and bases can increase the adsorption capacity of peanut shells against Pb(II) ions in different ways (Oktasari, 2018).

Previous research on the utilization of lignin from peanut shell waste as a Pb(II) adsorbent has been conducted by Oktasari (2018). The study conducted by Oktasari (2018) found Pb(II) ions in a solution, and peanut shells were used as adsorbents. Adsorption occurs on homogeneous surfaces with Langmuir and Freundlich isotherm models, while adsorption occurs on heterogeneous surfaces. Oktasari (2018) stated that by adding acid and alkaline reagents, the peanut shells used were activated. Activation is carried out to increase the capacity and effectiveness of adsorption. Once activated, peanut shells were characterized using Fourier Transform Infrared Spectroscopy (FTIR) spectroscopy. This is done to identify the functional groups present in it. To analyze experimental data, Langmuir and Freundlich's isothermic models were used. Several experimental conditions, including pH, adsorption time, and initial concentration of Pb(II) ions, were observed in peanut shells. The results showed that peanut shells activated with acids and bases were more capable of adsorption of Pb(II) ions than peanut shells without activation. In addition, the pH of the medium, the adsorption time, and the initial concentration of Pb(II) ions affect how effectively Pb(II) ions are adsorbed on the peanut shell.

Figure 1 shows how the concentration of Pb(II) metal ions affects the adsorption capacity of KKA (acid-activated), KKB (base-activated), and KK adsorbents. The results showed that the concentration of Pb(II) metal ions was positively correlated with the amount of metal residue not adsorbed by KK, KKA, and KKB adsorbents. However, the results also showed that the adsorption capacity of Pb(II) in KKB adsorbents is greater than in KKA adsorbents. The highest Pb(II) adsorption KK 1.465 mol/g, KKA 1.248 mol/g, KKB .543 mol/g. so it can be concluded that the concentration of Pb(II) metal ions affects the adsorption capacity of the three types of adsorbents. For higher concentrations of Pb(II) metal ions, KKB adsorbents have a greater adsorption capacity than KK and KKA.

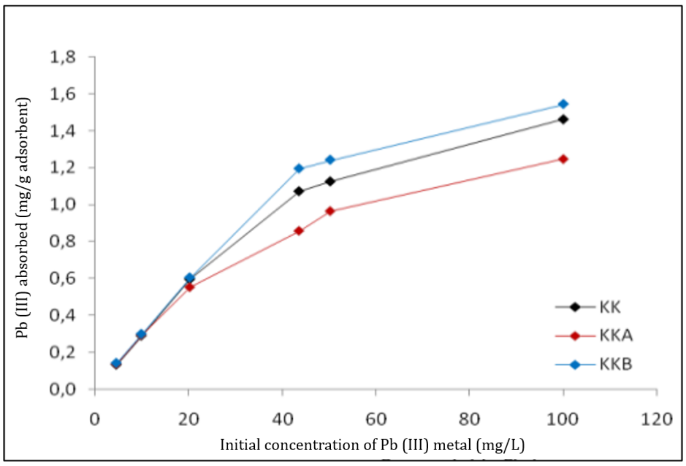

Figure 1. The Effect of Pb(II) Metal Ion Concentration on the Adsorption Capacity of KK, KKA (acid-activated), and KKB (base-activated) Adsorbents (Oktasari, 2018)

Cacao Peel Waste as Copper (Cu) Heavy Metal Adsorbent

Cocoa peel waste can act as a heavy metal adsorbent because it contains lignin compounds that have adsorption properties against heavy metals such as Cu. Lignin is a polymeric compound found in plant cell walls and has a complex chemical structure. The complex chemical structure of lignin gives it the ability to bond with heavy metals through strong chemical bonds. In the research by Deritawati, Waliyadin, Rasyid, & Nurjannah (2017), lignin was extracted from cocoa fruit peel waste and used as an adsorbent of Cu metal. To improve adsorption capacity, $CaCO_3$ is added.

The previous research by Deritawati, Waliyadin, Rasyid, & Nurjannah (2017), states that the process of absorption of Cu by lignin was carried out by contacting Cu solution with lignin at different pH variations and contact times. Lignin was isolated from cocoa peel waste using NaOH and H_2SO_4. Next, the dried lignin is contacted with a sulfur solution at variable time and pH. Research findings suggest that contact time and pH affect the amount of sulfur adsorbed by lignin. The longer the contact between the sulfur and lignin solution, the more sulfur is adsorbed by lignin. While at alkaline pH, the working power of lignin adsorbents will decrease, at acidic pH, the working power will increase. The study found that the pH of solution 6 is the best place for the absorption of Cu metal by lignin, and the ideal contact time is 40 minutes.

The adsorption mechanism of lignin as Cu adsorbent is suspected through several mechanisms, namely ionic adsorption, complex adsorption, and covalent adsorption. Ionic adsorption occurs when Cu metal ions bind to negatively charged lignin functional groups, such as carboxylate and phenolic groups. Adsorption complexation occurs when Cu metal ions form complexes with lignin functional groups, such as hydroxyl and amine groups. Covalent adsorption occurs when a covalent bond is formed between Cu metal ions and lignin functional groups, such as amine and sulfonate groups (Deritawati, Waliyadin, Rasyid, & Nurjannah, 2017).

Figure 2 shows the relationship of contact time with % absorption in the previous research by Deritawati, Waliyadin, Rasyid, & Nurjannah (2017) states that the process of Cu metal by lignin brown fruit skin. Combining lignin with Cu samples for ten, twenty, and thirty minutes showed significant increases in percent absorption, 83.67, 84.81, and 88.09, respectively. This suggests that the length of contact between the Cu and lignin solutions indicates that more Cu is adsorbed by lignin. In the process of absorption of Cu metal by lignin, the ideal contact time is 40 minutes. The previous research by Deritawati, Waliyadin, Rasyid, & Nurjannah (2017) states that $CaCO_3$ was also used as an additive in the process of absorption of Cu metal by lignin. The addition of $CaCO_3$ to the process of absorption of Cu metal by lignin can increase the efficiency of Cu metal absorption by lignin. The results showed that the addition of $CaCO_3$ at optimum pH (pH 6) increased the absorption of Cu metal in solution from 90.46% to 95.64%.

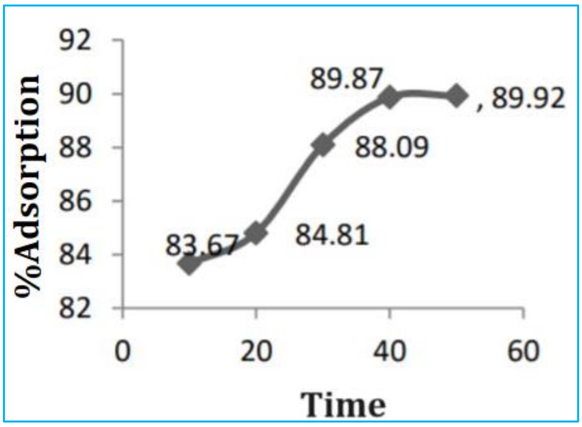

Figure 2. Contact Time Relationship with %Absorption (Deritawati, Waliyadin, Rasyid, & Nurjannah, 2017)

Coconut Shell Waste as Iron (Fe) Heavy Metal Adsorbent

Coconut shell waste can act as a heavy metal adsorbent because it has good adsorption properties. This is the result of the large surface area of the fine coconut shell powder, which allows for better absorption of ferrous (III) metal ions (Afriany, 2017). The use of coconut shells as an adsorbent of Fe(III) iron ions can help in everyday life, especially in overcoming the problem of heavy metal pollution. Excessive iron content in water can cause rust on clothes, and porcelain, and can be harmful to the body if too much. In research conducted by Mastiani, Amalia, & Rosahdi (2018), coconut shell waste was used as an adsorbent to reduce the concentration of Fe(III) metal ions in water.

In the study of Mastiani Amalia, & Rosahdi (2018), preliminary treatment was carried out on coconut shells to increase the effectiveness of adsorption, such as designation, charcoal, and calcined at certain temperatures. The results of Atomic Absorption Spectroscopy (AAS) analysis showed that adsorbents from coconut shell material that had been activated with NaOH had better effectiveness in reducing the concentration of Fe(III) metal ions. Thus, the use of coconut shells as an adsorbent can help reduce the risk of exposure of the human body to harmful heavy metals. In addition, the use of coconut shells as adsorbents is also an environmentally friendly and economical alternative to overcoming the problem of heavy metal pollution.

In the study of Mastiani, Amalia, & Rosahdi (2018), lignin isolation from coconut shell waste was carried out using the delignization method. The designation process is carried out by boiling coconut shell powder in a 2% NaOH solution for 2 hours, then filtering and cleaning with water to neutral pH. After that, coconut shell powder was activated with 0.1 M NaOH for 24 hours to increase adsorption effectiveness.

The mechanism of adsorption of heavy metal Fe(III) using lignin from coconut shell waste can occur because coconut shell waste has hydroxyl and carboxyl functional groups that can bind to Fe(III) metal ions through chemical bonds. In addition, the large surface area of fine coconut shell powder also allows physical adsorption, namely the absorption of Fe(III) metal ions on the adsorbent surface through van der Waals. The previous research by Mastiani, Amalia, & Rosahdi (2018) stated that the absorption of Fe(III) metal ions in adsorbents from coconut shell material that had been activated with NaOH had better effectiveness compared to unactivated adsorbents (Figure 3). The best unactivated adsorption absorption occurs at 600 C, with one hundred percent adsorbent efficiency. This is based on the results of effective treatment at 600 without activation, where more carbon is lost and reduces impurities, so this temperature is good for adsorbents.

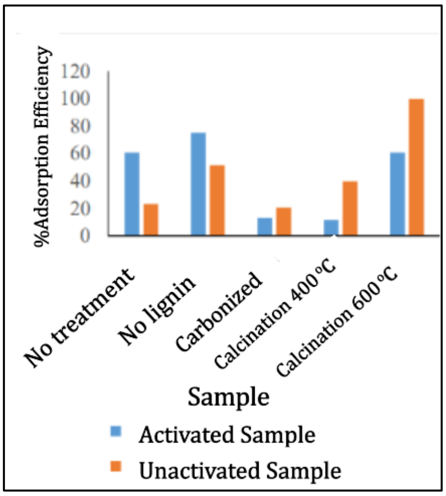

Figure 3. The Adsorption Efficiency Curve is Not Activated and Activated (Mastiani, Amalia, & Rosahdi, 2018)

Rice Husk Waste as Cadmium (Cd) Heavy Metal Adsorbent

According to Utomo & Fadila (2020), lignin in rice husk waste has aromatic rings and hydroxyl groups that can bond to metal ions. Therefore, lignin from rice husks can be developed to serve as an adsorbent against cadmium and other heavy metals. In Utomo & Fadila (2020) research, after isolating lignin from rice husks using NaOH, ethanol, and acetic acid solvents, lignin's ability as a Cd(II) metal adsorbent was tested using the AAS instrument, which stands for atomic absorption spectroscopy.

The ability of lignin as an absorbent agent was studied by isolating lignin from rice husks using solvents NaOH, ethanol, and acetic acid. The previous research by Utomo & Fadila (2020) showed that lignin from rice husks isolated using NaOH solvent had better adsorption capacity against Cd(II) metal compared to lignin isolated using ethanol and acetic acid solvents. Lignin from rice husks isolated using NaOH solvent has the highest adsorption capacity for adsorbents A and B at concentrations of 2.0 ppm, 1,037 mg/g, and 1,052 mg/g, respectively. According to Table 1, lignin is used as an adsorbent because it can reduce Cd^{2+} metal ions in solution. This occurs due to the interaction of electrostatic forces between the active group –OH and the metal ion Cd^{2+}.

Table 1. Adsorbent capacity value data A and B (Utomo & Fadila, 2020)

Types of Adsorbents	M Adsorbent (g)	Initial Conc. (ppm)	Final Conc. (ppm)	Adsorption Capacity (mg/g)
A	0,5	0,5	0,0392	0,277
	0,5	1,0	0,1200	0,528
	0,5	1,5	0,1864	0,788
	0,5	2,0	0,2719	1,037
B	0,5	0,5	0,0432	0,274

0,5	1,0	0,1211	0,527
0,5	1,5	0,1917	0,785
0,5	2,0	0,2466	1,052

Palm Oil Empty Bunch as Mercury (Hg) Heavy Metal Adsorbent

Palm oil empty bunch waste can act as a heavy metal adsorbent because it contains lignin, cellulose, and hemicellulose compounds which are the main constituent components of Empty Fruit Bunch (EFB). Because EFB contains active groups –OH and –COOH, lignocellulose compounds, the main component of EFB, can adsorb heavy metals, particularly Mercury (Hg). To activate the charcoal of empty oil palm bunches (EFB), sodium acetate salt solution is added. Therefore, unused palm oil bunch waste can be used as Hg adsorbent through the charcoal activation process.

The adsorption capacity is influenced by the variation in the mass of activated charcoal adsorbents in empty oil palm bunches. Oktasari 2018 the second optimum mass, 6 grams, has an adsorption capacity of 599.944 mg g-1, indicating that the more adsorbent mass used, the more adsorption capacity produced. However, keep in mind that the maximum adsorption capacity that an adsorbent can achieve is its limit.

In Gova & Oktasari (2the process of making Hg adsorbents from empty oil palm bunch waste begins by drying them to a moisture content of 10%. Then, the waste is cut and put in the oven at 500°C for two hours to produce a palm oil empty fruit bunch (EFB). Next, sodium acetate salt solution (CH_3COONa) is added as an activator and heated at 800 °C for one hour.

After the activated charcoal of empty oil palm bunches is used as an adsorbent for Hg heavy metals, the reaction mechanism between the activated charcoal of empty oil palm bunches and Hg heavy metals causes the adsorption process to occur. In the adsorption process, Hg heavy metal ions in solution will stick to the surface of activated charcoal and form a thin layer called the adsorption layer. The interaction between the surface of activated charcoal and Hg heavy metal ions occurs due to the attraction between the positive charge on Hg heavy metal ions and the negative charge on the surface of activated charcoal (Gova & Oktasari, 2019).

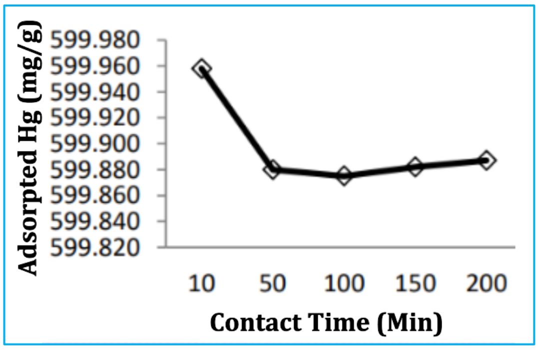

Figure 4. Graph of determination of contact time with mercury metal entangled (Gova & Oktasari, 2019)

Figure 4 shows that the best adsorption of mercury metal occurs at minute ten, with an absorption value of 599.958 mg g-1. During contact of fifty to twenty minutes, there is no significant increase in the adsorption of mercury heavy metals, since adsorbents have reached a saturation point where they can no longer adsorb heavy metals. In theory, as contact time increases, the adsorbate often interacts with the adsorbent, thereby increasing the amount of mercury trapped by the adsorbent. However, the study by Gova & Oktasari (2019) found that the best time is at the beginning of a 10-minute contact.

Sustainable Approach

Utilizing lignin as an adsorbent for heavy metals, sourced from organic waste, represents a sustainable approach with multifaceted benefits. Lignin, a complex polymer abundant in plant cell walls, particularly in wood, is derived from organic waste materials, making it a renewable and eco-friendly resource. By repurposing this waste product, the approach addresses two critical environmental concerns simultaneously: the effective removal of heavy metals and the reduction of organic waste Naseer et al., (2019). The sustainable nature of this method extends beyond the adsorption process. Lignin, with its diverse functional groups, offers a versatile solution for capturing a wide range of heavy metal pollutants Alsulaili, Elsayed, & Refaie (2023). The abundance of hydroxyl, methoxyl, and phenolic groups in lignin enhances its adsorption capacity and makes it adaptable to various metal ions. This not only contributes to environmental remediation but also underscores lignin's efficacy in mitigating pollution.

Moreover, the potential for regeneration and reusability of lignin as an adsorbent amplifies its sustainability profile. The ability to recover and reuse lignin in multiple adsorption cycles adds an economic and environmental dimension to the approach Fouda-Mbanga, Prabakaran, Pillay (2021)). This characteristic is particularly valuable in the context of heavy metal removal, where the long-term effectiveness and resource efficiency of adsorbents are essential considerations. The sustainability of this approach is further highlighted by the fact that lignin is obtained from organic waste, aligning with the principles of a circular economy. By transforming waste into a valuable resource, the method not only addresses environmental pollution but also contributes to a more sustainable and responsible use of resources. This aligns well with contemporary efforts to transition towards greener and more circular practices across various industries (Agasti, 2021).

The manuscript highlights the increasing concern about heavy metal pollution due to industrial activities and population growth. It emphasizes the adverse impact of heavy metals on the environment, ecosystems, and human health, with specific examples such as lead, mercury, cadmium, iron, and copper. Additionally, it connects heavy metal pollution to defense infrastructure, citing its potential to disrupt operational readiness and impact equipment functionality within the defense sector.

Raising awareness within the Indonesian National Armed Forces (TNI) regarding handling heavy metal pollution involves a multi-faceted approach. It requires educational programs, integration of eco-friendly practices, fostering research initiatives, collaboration with stakeholders, and implementation of stringent policies to promote environmental responsibility within defense operations. This structured strategy aims to instill a culture of environmental consciousness within TNI, ensuring the protection of both national security interests and the environment.

To address heavy metal pollution and its impact on defense infrastructure, a comprehensive strategy is proposed, beginning with education and training programs integrated into the TNI curriculum. These programs will offer specialized modules focusing on environmental conservation, elucidating heavy metal pollution sources, effects, and mitigation strategies within defense activities. Collaborations with environmental experts and organizations will bolster awareness campaigns, underscoring the direct influence of heavy metal pollution on defense operations. Integration of environmental practices will follow suit, infusing routine exercises, operations, and maintenance procedures with considerations aimed at curtailing heavy metal release. Waste management protocols will be emphasized, fortifying defense operations against heavy metal contamination and advocating eco-friendly approaches. Further, the establishment of guidelines endorsing sustainable defense practices will be pivotal in reducing heavy metal emissions. Research and development initiatives will concentrate on eco-friendly materials and innovative technologies to minimize heavy metal usage, nurturing a culture of sustainability within TNI. Collaborations with governmental bodies, academic institutions, and industry partners will facilitate the exchange of knowledge and best practices in heavy metal pollution mitigation. Finally, policy implementation and compliance measures will be introduced mandating environmentally conscious practices across all tiers of defense operations, coupled with regular audits to ensure adherence to environmental regulations and robust heavy metal pollution mitigation strategies.

Addressing heavy metal pollution stemming from military activities is imperative for environmental preservation. Leveraging organic waste materials like peanut shells, cocoa pod shells, coconut shells, rice husks, and empty oil palm fruit bunches as effective adsorbents for specific heavy metals—such as Pb, Cu, Fe, Cd, and Hg—presents an eco-friendly avenue for mitigation. Understanding the distinctive adsorption capacities of each material is pivotal for the Indonesian National Armed Forces (TNI) to manage environmental concerns tied to defense operations. Evaluating the potential of peanut shell waste to adsorb Pb(II) ions, examining cocoa pod shells' capacity for Cu metals, and utilizing coconut shells for Fe(III) ions offer promising environmentally responsible solutions. Additionally, assessing the capabilities of rice husk waste for Cd(II) ions and exploring the use of empty oil palm fruit bunches for Hg metals call for strategic measures to curtail environmental impacts caused by defense activities. Implementing these waste materials as adsorbents necessitates a thorough assessment of their applicability in defense contexts, urging the TNI to prioritize eco-friendly practices and responsible environmental management throughout their operations.

Heavy metal pollution profoundly impacts defense infrastructure, from storage to logistics and materials within the TNI equipment. The accumulation of heavy metals like lead, mercury, cadmium, iron, and copper, originating from various sources, poses a severe threat. These contaminants, when excessively present, can impair equipment functionality, reduce operational readiness, and curtail tactical capabilities within defense environments. The toxic nature of heavy metals, known for causing nervous system disorders, reproductive complications, organ damage, and elevated cancer risks in humans, translates to potential risks within defense setups. When heavy metal-laden pollution enters water systems and settles in sediment, it magnifies over time, accumulating within living organisms. Consequently, it becomes a long-lasting and pervasive hazard. Addressing heavy metal pollution in defense infrastructure becomes crucial to maintaining operational readiness and protecting personnel. Adopting sustainable approaches like utilizing lignin from organic waste materials as adsorbents offers a promising avenue to mitigate heavy metal risks effectively and sustainably within defense environments. Such measures align with the dual objectives of ensuring national security while championing environmental preservation.

The perilous ramifications of heavy metal pollution underscore the need for an innovative remedy employing lignin sourced from organic waste as a proficient adsorbent for these contaminants. Beyond its environmental implications, this solution transcends conventional paradigms by showing promise for defense and security domains. The hazards articulated—stemming from the industrial discharge of heavy metals—expose the vulnerability of ecosystems, posing profound threats to biodiversity and ecosystem health. Simultaneously, the bioaccumulation of heavy metals in organisms represents a silent yet potent menace, predisposing individuals to a range of severe health afflictions, including neurological disorders, organ degradation, reproductive anomalies, and heightened cancer risks. Furthermore, within the realm of defense infrastructure, the infiltration of heavy metals initiates a cascade of operational impediments, endangering readiness, impairing equipment functionality, and limiting tactical capabilities, thereby emphasizing the urgent need for a comprehensive solution.

The proposed avenue of leveraging lignin extracted from diverse organic waste repositories emerges as a beacon of hope amid these challenges. With its organic origin and abundant availability in waste streams, lignin epitomizes a sustainable antidote to heavy metal encroachment. Operating through a sophisticated adsorption mechanism, wherein its intricate functional groups engage in ionic, complexation, and covalent bonding with heavy metals, activated lignin from organic waste robustly augments adsorption capacities for specific heavy metals. Its renewable nature and multifaceted functionality not only empower it to capture diverse pollutants effectively but also herald its potential for regeneration and reusability, aligning seamlessly with circular economy principles. However, the path towards seamless integration into defense and security frameworks necessitates a concerted effort to bridge the chasm between theoretical prowess and practical implementation, urging a focused trajectory for scalable, real-world solutions in these critical domains.

The pervasive impact of heavy metal pollution on defense environments resonates as a multifaceted challenge, undermining operational readiness and curtailing tactical capabilities. Infesting critical infrastructure and military systems, these noxious agents corrode functionality, rendering equipment less reliable or even inoperable, ultimately eroding readiness and impeding operational efficiency. Such contamination not only compromises immediate tactical prowess but also jeopardizes the durability and functionality of vital defense assets, amplifying vulnerabilities within defense frameworks (McKay et al., 2021). To counteract these pervasive threats, the integration of sustainable remedies like lignin-based adsorption sourced from organic waste emerges as a pivotal strategy. This innovative approach not only fortifies defense infrastructures against heavy metal incursions but also augments resilience, optimizing operational readiness, and bolstering the robustness of tactical capabilities. Leveraging lignin as an adsorbent embodies an environmentally conscious paradigm, offering an effective shield against heavy metal perils and fortifying defense systems against their insidious effects (Naseer et al., 2019).

The presence of heavy metals in defense environments poses a significant risk to military equipment functionality. Research has shown that heavy metal contamination, such as lead (Pb), mercury (Hg), cadmium (Cd), iron (Fe), and copper (Cu), can substantially impair the performance of defense systems. For instance, studies on various organic waste materials like peanut shells, cocoa peel waste, coconut shells, rice husks, and empty oil palm bunches demonstrate their potential as heavy metal adsorbents. Lignin, extracted from these waste sources, exhibits the capability to adsorb these metals effectively. For instance, in the case of Pb(II) ions, activation of peanut shells with acids or bases significantly increased their adsorption capacity. Similarly, lignin from cocoa peel waste showed a high adsorption capacity for Cu ions, while lignin from coconut shells displayed efficacy in adsorbing Fe(III) ions. Moreover, rice husk-derived lignin demonstrated promising adsorption capacities against Cd(II) ions, and lignin obtained from palm oil empty bunches exhibited potential in absorbing Hg ions. These studies emphasize the potential of lignin-based adsorbents derived from organic waste materials to counter heavy metal pollution effectively. Such an approach holds promise in mitigating the damaging effects of heavy metal contamination on military equipment within defense environments, thereby safeguarding operational functionality and tactical capabilities.

In conclusion, the utilization of lignin as an adsorbent for heavy metals extracted from organic waste represents a holistic and environmentally conscious strategy. From its renewable source to its versatile adsorption capabilities and potential for repeated use, lignin embodies a sustainable approach to addressing heavy metal pollution. As a key component in the circular economy, this method contributes to both environmental remediation and resource efficiency, making it a promising avenue for sustainable heavy metal removal in equipment, and defense industries to environmental issues.

In this research, a literature study was conducted on several organic waste materials used as heavy metal adsorbents. The primary focus was on peanut shell waste, cocoa pod shell waste, coconut shell waste, rice husk waste, and empty oil palm fruit bunch waste.

1. Peanut shell waste as lead (Pb) heavy metal adsorbent and the defense and security implications. Figure 1 illustrates how the concentration of Pb(II) metal ions affects the adsorption capacity of different adsorbents. The results indicate that the adsorption capacity of Pb(II) in acid-activated (KKA) and base-activated (KKB) adsorbents is noteworthy. This leads us to crucial considerations related to defense and security. The awareness of TNI in handling heavy metal pollution is essential. Does military training or equipment contribute to heavy metal pollution, and what steps should TNI take to mitigate these environmental impacts? Additionally, exploring the role of the defense industry in heavy metal pollution and suggesting strategies for environmentally responsible practices is crucial for sustainable defense operations.
2. Cacao peel waste as copper (Cu) heavy metal adsorbent defense and security implications. Figure 2 demonstrates the relationship of contact time with %absorption in the absorption process of Cu metal by lignin from cocoa peel waste. Understanding the impact of military activities on copper pollution and proposing measures to minimize this impact is crucial for defense and security. How can the defense sector adopt practices to reduce the environmental footprint of copper-related activities?
3. Coconut shell waste as iron (Fe) heavy metal adsorbent and the defense and security implications. Figure 3 presents the adsorption efficiency curve for both activated and unactivated coconut shell adsorbents. Considering the potential use of coconut shell waste adsorbents in defense applications, it's essential to assess the environmental impact of defense-related activities involving iron. Strategies for responsible waste management within the defense sector can contribute to environmental sustainability.
4. Rice husk waste as cadmium (Cd) heavy metal adsorbent and the defense and security implications. Table 1 provides adsorbent capacity data for different concentrations of Cd(II) metal using lignin from rice husks. Assessing the impact of defense activities on cadmium pollution and proposing measures to minimize this impact is crucial for defense and security.
5. Palm oil empty bunch as mercury (Hg) heavy metal adsorbent defense and security implications. Figure 4 depicts the graph of the determination of contact time with mercury metal entangled. Understanding the role of the defense sector in mercury pollution and proposing strategies for responsible mercury management is crucial for defense and security.

CONCLUSIONS, RECOMMENDATIONS, AND LIMITATIONS

The analysis brings to light a critical solution to heavy metal pollution: utilizing various organic waste materials as adsorbents for heavy metals. Groundnut husk waste, brown fruit skin waste, coconut husk waste, rice husk waste, and empty oil palm bundle waste demonstrate promise in adsorbing heavy metals due to the presence of lignin compounds within them. However, the methods of lignin separation and their specific adsorption capacities vary among these materials.

This study underscores the potential integration of heavy metal adsorption using lignin from organic waste into the domain of defense and security. It represents an ongoing effort to align environmental preservation with national security priorities. The comprehensive literature review conducted in this study illuminates the diverse capabilities of lignin-based adsorbents in mitigating heavy metal risks, spanning both environmental and defense dimensions.

Ultimately, this discovery emphasizes the latent potential in harnessing organic waste materials to uphold ecological balance and fortify defense infrastructure resilience. By merging sustainable initiatives with security needs, this research charts a path toward a future where innovation and environmental stewardship work hand in hand for the well-being of the planet and its inhabitants.

This discovery unearths the latent potential in harnessing organic waste materials to uphold ecological equilibrium and fortify defense infrastructure resilience. By synergizing sustainable initiatives with security requisites, this research delineates a path toward a future in which innovation and environmental guardianship synergistically advance the welfare of the planet and its inhabitants.

While the integration of organic waste materials, particularly lignin, for heavy metal adsorption, presents a promising avenue for environmental sustainability and defense infrastructure resilience, several limitations should be acknowledged:

1. Material-Specific Variability.
   The diverse organic waste materials investigated in this study exhibit unique properties and compositions. The variability in lignin content and quality among groundnut husk waste, brown fruit skin waste, coconut husk waste, rice husk waste, and empty oil palm bundle waste may impact the standardized application of adsorption techniques. The study recognizes the need for tailored approaches to maximize the efficacy of each organic material.
2. Site-Specific Applicability
   The effectiveness of lignin-based adsorbents may vary based on geographical and environmental factors. Local conditions, climate, and soil characteristics can influence the adsorption capacities and mechanisms. The study emphasizes the importance of site-specific assessments to ensure the practicality and efficiency of implementing these adsorbents in diverse locations.

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