Chitosan-Based Water Purification: Harnessing Indonesian Shrimp Shell Waste for Sustainable Water Management

Natasha Sebastian Haryanto[1],
Norbertus Krisnu Prabowo[2*]
[1]PENABUR Junior College Kelapa Gading, Jakarta, Indonesia,14240
[2]Department of Chemistry Education, State University of Jakarta, Indonesia
*Corresponding Author: natashasebastianharyanto@gmail.com

Abstract

In Indonesia, both urban and rural residents face a critical problem with water contamination. With rising levels of wastewater from domestic and industrial sources- particularly in developing countries like Indonesia- there is an urgent need to develop economical and sustainable methods of filtration. As one of the world's largest shrimp producers, Indonesia generates a significant amount of shrimp shell waste. Within this waste is chitin, a material that can be derived into a biopolymer known as chitosan. This byproduct has emerged as a popular, eco-friendly water filter for its biodegradability, non-toxicity, and availability. With this high supply industry, chitosan can be upcycled from waste streams into valuable water purifiers. This review identifies chitosan's efficiency in eliminating pollutants, with extensive heavy metal removal (Pb^{2+}, Cd^{2+}), its natural flocculating and antimicrobial properties. Phosphates and nitrates are also removed by chitosan-modified membranes, preventing agricultural runoff. However, limitations such as mechanical instability, pH-dependent efficiency, and high processing costs hinder large-scale application. Given its abundant supply in Indonesia, chitosan can be utilized to develop scalable water treatment solutions for pollution problems. This review addresses its applications, limitations, and policy recommendations for sustainable water management.

Keywords: STEM, Wastewater Treatment, Chitosan, Eco-friendly, Adsorbent, Sustainability

Structure of the paper

I. Introduction

As an archipelagic country, Indonesia is currently dealing with severe issues regarding water quality brought on by environmental degradation, agricultural runoff, and industrialization. Both environmental sustainability and public health are at risk by these factors. It has been discovered that several water bodies contain contaminants, such as heavy metals, organic pollutants, and microbial disease, that affect aquatic life and drinking water supplies. Chemical coagulation, activated carbon filtration, and membrane filtration are examples of traditional water treatment methods that frequently have high operating costs and adverse environmental effects, such as the production of toxic sludge (Veríssimo et al., 2021).

Chitosan, a biodegradable substance derived from chitin and present in large quantities in shrimp and crab shells, offers a promising substitute. Utilizing chitosan minimizes waste and sustainably addresses environmental issues, especially considering Indonesia's sizable shellfish industry (Suning et al., 2022). Due to its distinct physicochemical properties, chitosan has the potential to improve the quality of water in both residential and commercial settings (Nekvapil et al., 2021).

This research journal aims to examine the role of chitosan-based technologies in Indonesia's water purification efforts, focusing on their application in removing heavy metals, organic pollutants, and microbial contaminants. Additionally, the study explores the challenges hindering large-scale adoption and provides policy recommendations to facilitate the integration of chitosan-based water treatment systems in Indonesia. By leveraging Indonesia's abundant chitosan resources, sustainable water management solutions can be developed to address the nation's pressing water pollution issues (De Aguiar Saldanha Pinheiro et al., 2021).

A. Methodology of Literature Review

To support this review, a comprehensive literature analysis was conducted, focusing on the properties and role of chitosan in wastewater treatment technologies and the current policies and economy in Indonesia. Data were sourced from reputable scientific databases, including Science Direct, Google Scholar, Research Gate, and official Indonesian government websites. In searching papers, the keywords "chitosan," "wastewater treatment," "sustainability," and "biopolymer adsorbent" were highly focused on. Publications published during the last two decades, from 2002 to 2025, were mostly focused on in the review.

Inclusion criteria consisted of:

1. Studies that focus on materials derived from chitosan for water or wastewater purification,
2. Articles that present case studies or experimental results post-observation,
3. Papers discussing the implementation of chitosan into the water purification industry, especially in developing countries.

Literature excluded includes non-peer-reviewed journals, studies, and articles not in English or Indonesian, and papers that do not focus on practical applications.

II. Properties and Mechanism of Chitosan

A. Physicochemical Properties of Chitosan

Chitosan is a very biocompatible, biodegradable, and adsorbable natural polysaccharide, especially for water treatment (Rhazi et al., 2002). Its amino ($-NH_2$) and hydroxyl (-OH) functional groups are accountable for effective adsorption of pollutants by the mechanisms of chelation, ion exchange, and flocculation (da Silva Alves et al., 2021). These properties make chitosan particularly suitable for wastewater treatment in Indonesia as an adsorbent for metal and dye (Zubair et al., 2020; Wani et al., 2023). Chitosan also possesses antimicrobial properties that enhance its possibility as a water disinfectant (Vidal et al., 2022).

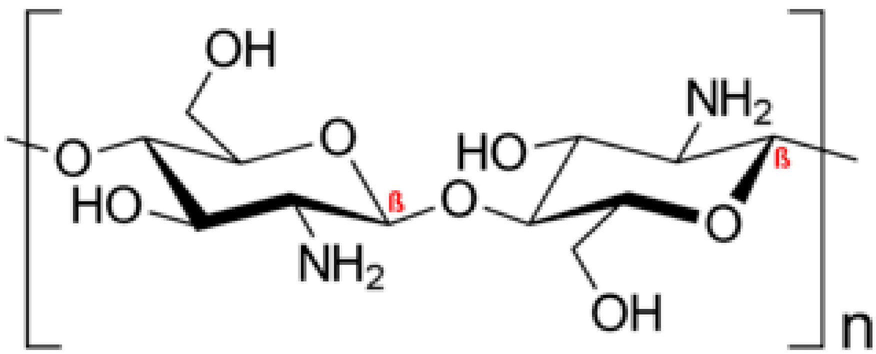

Figure 1. The chemical structure of chitosan

Major physicochemical factors that enhance chitosan's adsorption capacity as an adsorbent are:

- High surface area: Chitosan may be prepared in the form of powders, beads, or membranes, giving larger surfaces accessible for adsorption (Guibal, 2004).
- Positive charge under acidic conditions: Chitosan protonates in acidic conditions (pH <6.5) and is, therefore, highly effective at absorbing anionic pollutants such as heavy metal ions, phosphates, and dyes (Crini & Badot, 2008).
- Hydrophilicity: Hydroxyl groups enhance water retention capacity in chitosan, enabling diffusion and interaction of contaminants (Ren et al., 2020).

B. Adsorption Mechanism of Chitosan

Adsorption is the process by which molecules, ions, or particles adhere to the surface of a solid or liquid rather than being absorbed into it. The ability of chitosan to remove contaminants from water is primarily determined by three key adsorption mechanisms:

1. Chelation and Ion Exchange

Chelation is a chemical process in which molecules (chelating agents) attach to a metal ion using more than one bond, effectively trapping it and allowing it to be removed from a solution. Chitosan's amine groups ($-NH_2$) act as chelating sites that interact with metal ions such as lead (Pb^{2+}), cadmium (Cd^{2+}), and arsenic (As^{3+}) to create stable complexes (Bhatnagar & Sillanpää, 2009). This chelation process involves:

- The protonation of amine groups in acidic environments.

- The electrostatic attraction between positively charged chitosan molecules and negatively charged contaminants.
- The formation of stable coordinate bonds between metal ions and chitosan functional groups effectively immobilizes toxic metals and prevents their release into the water supply (Ngah et al., 2011).

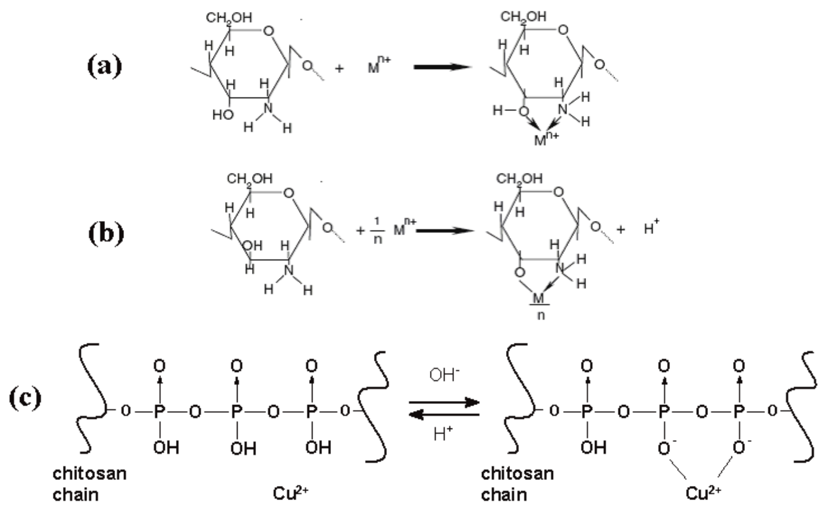

Figure 2. Diagram of ion exchange between Cu(II) and chitosan (Lee, 2001)

2. Flocculation and Coagulation

A flocculant, used in water treatment and other uses, is a chemical or other material added to a suspension to encourage suspended particles to come together and form larger, easily removable clumps called flocs. As a potent natural flocculant, chitosan increases the removal of suspended solids and organic matter from wastewater. The process involves:

- Charge neutralization
  - Chitosan's amine groups with positive charges are attracted to negatively charged particles (e.g., colloids, organic impurities, bacteria) (Goy et al., 2016).
- Aggregation
  - The neutralized particles form larger flocs that settle more rapidly and are easily separated by filtration.
- Adsorption bridging
  - Chitosan molecules span multiple particles, promoting floc growth and settling rates (Omer et al., 2022).

3. Antimicrobial Activity

Chitosan exhibits strong antimicrobial properties, making it useful in disinfecting water and reducing pathogen loads. The antimicrobial mechanisms include:

- Disruption of microbial cell membranes
  - Chitosan's positively charged molecules interact with negatively charged bacterial cell walls, leading to membrane disruption, leakage of intracellular contents, and eventual cell death (Leceta et al., 2013).
- Inhibition of microbial metabolism
  - Chitosan can bind essential nutrients and metal ions required for bacterial growth, effectively starving microbial populations (Goy et al., 2016).
- Biofilm inhibition
  - Chitosan prevents bacterial adhesion and biofilm formation, reducing the persistence of pathogenic microorganisms in water systems (Benhabiles et al., 2012).

III. Applications of Chitosan in Water Treatment

A. Removal of Heavy Metals

Water resources are under the severe threat of contamination due to pollution from industries like mining, textiles, and electroplating caused by heavy metals. Indonesian studies have demonstrated that chitosan is effective in adsorbing industrial waste water-borne heavy metals like lead (Pb), cadmium (Cd), and arsenic (As). According to studies, modified chitosan composites like chitosan and graphene oxide or alginate-based composites improve the effectiveness of metal removal and hence are suitable for commercial use (Fotodimas et al., 2024).

B. Treatment of Domestic Wastewater

Untreated household waste is one of the causes of waterborne diseases that affect both urban and rural communities. Chitosan-based flocculants have been employed to improve sedimentation and reduce microbial contamination, leading to safer alternatives to drinking water. Novel chitosan membranes loaded with silver nanoparticles were found to exhibit remarkable antibacterial activity in recent studies, making them a promising approach to decentralized water purification in remote areas (Topić Popović et al., 2023).

C. Agricultural Runoff Management

Excessive use of pesticides and fertilizer in the agricultural sector in Indonesia has also resulted in the pollution of water bodies with nutrients. Chitosan-based membranes and beads have proven to be promising adsorbent materials to reduce the risk of eutrophication by adsorbing phosphates and nitrates. Pilot studies have been conducted, such as chitosan-modified biofilters which have been placed in irrigation channels and have shown promise regarding reducing agrochemical runoff and improving water quality (E. Alkaya et al., 2016).

IV. Analysis and Discussion

A. Comparative Performance with Other Biopolymers

In comparison with other biological natural biopolymers such as alginate, cellulose, or starch derivatives, chitosan is more likely to exhibit greater metal-binding capacities due to its free amine groups (Crini & Badot, 2008). Chitosan was also observed to possess more than 90% removal efficiency for lead (Pb^{2+}) and cadmium (Cd^{2+}) ions, which was superior to alginate under similar conditions (Ngah & Fatinathan, 2008). However, alginate and cellulose-based materials tend to show better mechanical stability and water retention properties, which can be advantageous in specific treatment processes, such as membrane filtration or biofilm-based systems (Mohan et al., 2011).

On the other hand, hybrid materials such as graphene oxide (GO)-chitosan composites and magnetic chitosan beads have shown greater surface area and reusability. As an example, chitosan-GO composites have shown 30–50% greater adsorption rates for certain dyes compared to unmodified chitosan (Thakur et al., 2019). However, the synthesis for these materials requires advanced laboratory equipment and costly precursors, having a large barrier to entry for scale-ups in developing countries such as Indonesia.

B. Evaluation of Modification Methods

Chitosan modification methods- ranging from physical blending to chemical grafting- significantly influence its adsorption efficacy, stability, and cost-effectiveness. For example:

- Crosslinking with epichlorohydrin or glutaraldehyde increases the strength of the structure but can reduce biocompatibility due to toxic residues (Varma et al., 2004).
- Metal oxide addition (e.g., Fe_3O_4 or TiO_2) increases separability by magnet and photocatalyst activity but carries risks for secondary pollution if the nanoparticles are not entirely contained (Tian et al., 2009).
- Compatibility with naturally occurring materials like bentonite or rice husk ash can reduce cost and improve performance for multi-contaminant systems, presenting a practical route for local adaptation.

Despite all these advances, it is not widely discussed in the literature on the cost-benefit of each modification strategy, especially for small-scale or decentralized wastewater treatment plants like the ones commonly located in Indonesia. Some studies provide a comparison between the enhancement of treatment efficiency and the associated increase in material cost, leaving a gap in real-world decision-making by policymakers and industry operators (Kurniawan et al., 2006).

V. Case Studies and Implementation Challenges

Certain Indonesian universities and research centers have piloted chitosan-based water treatment experiments. In particular, a project in Central Java was able to install working chitosan-based filtration units in small-scale water treatment plants. However, concerns over scalability, cost, and awareness remain stumbling blocks to large-scale applications. In addition, the lack of regulatory policies for biopolymer-based water treatment poses obstacles to commercialization (Yousaf et al., 2022).

A. Economical Challenges

Economically speaking, it is costly to achieve high-purity chitosan since it relies on foreign reagents and the irregular quality of domestic crustacean waste. As of 2025, pure chitosan powder can be supplied at around USD 3-4 per kilogram, but chitosan composites that have been modified, such as those that include nanoparticles, can be over USD 12-15 per kilogram and less suitable for municipal-level deployment without subsidy (Tan et al., 2021).

This economic adversity is compounded by the devaluation of the Indonesian Rupiah (IDR) against the U.S. dollar. The Rupiah, as of early 2025, was around 16,000 per USD, registering a sharp declining trend that elevates the price of imported materials and equipment required in producing chitosan. This devaluation directly contributes to the inflation of production expenses, lowering the competitiveness and accessibility of chitosan-based technologies in domestic markets (Jakarta Globe, 2024).

Moreover, regulatory uncertainty regarding the classification and certification of biopolymer-based treatment systems are also barriers. In Indonesia, there has not been an established standard procedure for testing biopolymer adsorbents, making industries and municipalities hesitant to use these materials untouched as those conducted in Yogyakarta and East Java emphasize the requirement for policy interventions that are based on support as well as financing incentives to spur innovation into action (Silva et al., 2021).

B. Contextual Stability in Indonesia

In Indonesia- where crustacean waste from shrimp and crab processing industries is mass produced- chitosan is a locally accessible, eco-friendly alternative for water treatment. Its use, however, remains largely confined to pilot plants and laboratory experiments in Indonesia and other developing countries. There are few, if any, studies that account for the prevailing environmental conditions of Indonesian wastewater streams, e.g., organic load high, tropical temperatures, or seasonality of pollutant concentration.

In addition, the water pH in most Indonesian rivers is near neutrality or slightly alkaline, in which the effectiveness of chitosan decreases due to the deprotonation of its amine groups (Babel & Kurniawan, 2003). Indonesia's decentralized water treatment system also poses unique challenges for the realization of advanced chitosan composites. The cost of material preparation, transportation, and trained personnel to operate such systems must be considered, especially because Indonesia is a developing country that may lack access to such necessities. There is also the need for systems that not only function but are simple to use and maintain by local communities with minimal technical support.

VI. Future Prospects and Policy Recommendations

To enhance chitosan water treatment uptake, Indonesian policymakers should advance support for research grants, promote industry partnerships for chitosan production, and establish water treatment programs at the community level. Further research into ways of modifying chitosan, such as nanocomposite formulations, would enhance efficiency and cost savings. The offer of incentives by the government to the seafood processing industry to transform crustacean waste into chitosan would also stimulate quicker production and application in water treatment (De Aguiar Saldanha Pinheiro et al., 2021).

A. Policy Recommendation

To further develop chitosan-based water treatment technology use in 2025 and beyond, ensuring that policy proposals are aligned with Indonesia's *Rencana Pembangunan Jangka Menengah Nasional* (RPJMN) 2025-2029 and the newly being prepared updated National Industrial Policy, which targets environmental sustainability and the implementation of green technologies (Bappenas, 2024) is imperative. Even while there is growing interest in green treatment processes, a broad gap remains in the regulatory incentives for green innovations in water treatment. This can be filled by the Ministry of Environment and Forestry by integrating chitosan-based treatment systems in the overhauled Prokasih (Clean River Program), which is being re-written in 2025 to ensure decentralized and nature-based solutions for community-scale wastewater treatment plants (KLHK, 2025).

In addition, strategic collaboration among ministries, like the Ministry of Marine Affairs and Fisheries, to facilitate crustacean waste valorization, and the Ministry of Industry, can catalyze the use of a circular economy method that serves both environmental performance as well as rural employment creation. Government-supported incentives and public-private collaborations, such as R&D tax credits and competitive grants, will be crucial in accelerating innovation in biopolymer technologies and enabling local industries to scale up production sustainably (Ministry of Industry, 2025).

VII. Conclusion

Chitosan offers massive potential as an Indonesian water treatment technology. Naturally abundant, biocompatible, and highly effective in removing pollutants, it presents a sustainable option over conventional technologies. With the drive of research and policymaker awareness, chitosan technologies have the potential to significantly improve water quality and human health in Indonesia. By integrating circular economy philosophies, the application of chitosan can resolve in parallel waste management and environmental sustainability challenges.

VIII. References

[1]. Veríssimo, N. V., Mussagy, C. U., Oshiro, A. A., Mendonça, C. M. N., Santos-Ebinuma, V. de C., Pessoa, A., Oliveira, R. P. de S., & Pereira, J. F. B. (2021, November 9). *From Green to Blue Economy: Marine biorefineries for a sustainable ocean-based economy*. Green Chemistry. https://doi.org/10.1039/D1GC03191K

[2]. Suning, S., Walujo, D. A., Rohmadiani, L. D., & Prihono, P. (2022). Circular economy policy of shrimp waste as an effort to implement Green Economy. Jurnal Kawistara. https://doi.org/10.22146/kawistara.68866

[3]. Yousaf, Z., Mădălina, B., Mihai, D., Maria-Luiza, H., Cristina, Ștefan M., & Constantin, P. (2022, September 2). Pollution reduction as catalyst between environmental resources conservation efforts and sustainable development: Investigation of energy firms in circular economy. MDPI. https://doi.org/10.3390/en15176410

[4]. De Aguiar Saldanha Pinheiro, A. C., Martí-Quijal, F. J., Barba, F. J., Tappi, S., & Rocculi, P. (2021, August 29). Innovative Non-Thermal Technologies for recovery and valorization of value-added products from crustacean processing by-products-an opportunity for a circular economy approach. MDPI. https://doi.org/10.3390/foods10092030

[5]. Nekvapil, F., Ganea, I.-V., Ciorîță, A., Hirian, R., Ogresta, L., Glamuzina, B., Roba, C., & Cintă Pinzaru, S. (2021, August 13). Wasted biomaterials from crustaceans as a compliant natural product regarding microbiological, antibacterial properties and heavy metal content for reuse in Blue Bioeconomy: A preliminary study. MDPI. https://doi.org/10.3390/ma14164558

[6]. Wani, A.K., Akhtar, N., Mir, T.u.G. et al. Eco-friendly and safe alternatives for the valorization of shrimp farming waste. Environ Sci Pollut Res 31, 38960–38989 (2024). https://doi.org/10.1007/s11356-023-27819-z

[7]. Fotodimas, I., Ioannou, Z., & Kanlis, G. (2024, August 12). A review of the benefits of the sustainable utilization of shrimp waste to produce novel foods and the impact on human health. MDPI. https://doi.org/10.3390/su16166909

[8]. E. Alkaya, G.N. Demirer,(2016, July 14). Minimizing and adding value to seafood processing wastes. Food and Bioproducts Processing. https://doi.org/10.1016/j.fbp.2016.07.003

[9]. Topić Popović, N., Lorencin, V., Strunjak-Perović, I., & Čož-Rakovac, R. (2023, January 2). Shell Waste Management and utilization: Mitigating organic pollution and enhancing sustainability. MDPI. https://doi.org/10.3390/app13010623

[10]. Vidal, J. L., Jina , T., Lama, E., Mooresa, A., & Kertonc, F. (2022, July 20). Blue is the new green: Valorization of crustacean waste. Current Research in Green and Sustainable Chemistry. https://doi.org/10.1016/j.crgsc.2022.100330

[11]. M. Rhazi, J. Desbrières B, A. Tolaimate, M. Rinaudo, P. Vottero, A. Alagui, El Meray (2002, February 7). Influence of the nature of the metal ions on the complexation with

chitosan.: Application to the treatment of liquid waste. https://doi.org/10.1016/S0014-3057(02)00026-5
[12]. da Silva Alves, D. C., Healy, B., Pinto, L. A. d. A., Cadaval, T. R. S., Jr., & Breslin, C. B. (2021). Recent Developments in Chitosan-Based Adsorbents for the Removal of Pollutants from Aqueous Environments. https://doi.org/10.3390/molecules26030594
[13]. Mukarram Zubair, Ihsanullah Ihsanullah, Hamidi Abdul Aziz, Mohd Azmier Ahmad, Mamdouh A. Al-Harthi (2020 September 12). Sustainable wastewater treatment by biochar/layered double hydroxide composites: Progress, challenges, and outlook. https://doi.org/10.1016/j.biortech.2020.124128
[14]. Benhabiles, M. S., Salah, R., Lounici, H., Drouiche, N., Goosen, M. F. A., & Mameri, N. (2012). Antibacterial activity of chitin, chitosan, and their oligomers prepared from shrimp shell waste. https://doi.org/10.1016/j.foodhyd.2012.02.013
[15]. Bhatnagar, A., & Sillanpää, M. (2009). Applications of chitin- and chitosan-derivatives for the detoxification of water and wastewater – A short review. Advances in Colloid and Interface Science. https://doi.org/10.1016/j.cis.2009.09.003
[16]. Crini, G., & Badot, P. M. (2008). Application of chitosan, a natural aminopolysaccharide, for dye removal from aqueous solutions by adsorption processes using batch studies: A review. https://doi.org/10.1016/j.progpolymsci.2007.11.001
[17]. Goy, R. C., Morais, S. T. B., & Assis, O. B. G. (2016). Evaluation of the antimicrobial activity of chitosan and its quaternized derivative on E. coli and S. aureus growth. https://doi.org/10.1016/j.bjp.2015.09.010
[18]. Guibal, E. (2004). Metal ion interactions with chitosan—a review. https://doi.org/10.1016/j.seppur.2003.10.004
[19]. Leceta, I., Guerrero, P., Ibarburu, I., Dueñas, M. T., & de la Caba, K. (2013). Characterization and antimicrobial analysis of chitosan-based films. https://doi.org/10.1016/j.jfoodeng.2013.01.022
[20]. Ngah, W. W., Teong, L. C., & Hanafiah, M. A. K. M. (2011). Adsorption of dyes and heavy metal ions by chitosan composites: A review. https://doi.org/10.1016/j.carbpol.2010.11.004
[21]. Omer, A. M., Dey, R., Eltaweil, A. S., Abd El-Monaem, E. M., Ziora, Z. M. (2022). Insights into recent advances of chitosan-based adsorbents for sustainable removal of heavy metals and anions. https://doi.org/10.1016/j.arabjc.2021.103543
[22]. Rinaudo, M. (2006). Chitin and chitosan: Properties and applications. https://doi.org/10.1016/j.progpolymsci.2006.06.001
[23]. Lee, S., Mi, F., Shen, Y., Shyu, S. (2001). Equilibrium and kinetic studies of copper(II) ion uptake by chitosan-tripolyphosphate chelating resin. https://doi.org/10.1016/S0032-3861(00)00402-X
[24]. Li, Z., Qin, R., Xue, J., Lin, C., & Jiang, L. (2025). Chitosan-Based Hydrogel Beads: Developments, Applications, and Challenges. https://doi.org/10.3390/polym17070920
[25]. Babel, S., & Kurniawan, T. A. (2003). Low-cost adsorbents for heavy metals uptake from contaminated water: A review. https://doi.org/10.1016/S0304-3894(02)00263-7
[26]. Kurniawan, T. A., Chan, G. Y. S., Lo, W. H., & Babel, S. (2006). Physico-chemical treatment techniques for wastewater laden with heavy metals. https://doi.org/10.1016/j.cej.2006.01.015
[27]. Tian, S., Jiang, P., Ning, P., Su, Y. (2009). Enhanced adsorption removal of phosphate from water by mixed lanthanum/aluminum pillared montmorillonite. https://doi.org/10.1016/j.cej.2009.02.006

[28]. Mohan, D., Sarswat, A., Singh, V. K., Alexandre-Franco, M., & Pittman Jr., C. U. (2011). Development of magnetic activated carbon from almond shells for trinitrophenol removal from water. https://doi.org/10.1016/j.cej.2011.06.054
[29]. Ngah, W. S. W., & Fatinathan, S. (2008). Adsorption of Cu(II) ions in aqueous solution using chitosan beads, chitosan–GLA beads and chitosan–alginate beads. https://doi.org/10.1016/j.cej.2007.12.006
[30]. Varma, A. J., Deshpande, S. V., & Kennedy, J. F. (2004). Metal complexation by chitosan and its derivatives: A review. https://doi.org/10.1016/j.carbpol.2003.08.005
[31]. Thakur, K., Kandasubramanian, B. (2019). Graphene oxide-based composites for the removal of contaminants from water: A review. https://doi.org/10.1021/acs.jced.8b01057
[32]. Jakarta Globe. (2024). Indonesia's Rupiah Depreciates as Economic Growth Slows in 2024. https://jakartaglobe.id/business/dpr-and-government-set-2025-rupiah-exchange-rate-at-rp-16000
[33]. Tan, H., Yin, Z., Muhamad, N., & Liew, F. (2021, November 2). Potential economic value of chitin and its derivatives as major biomaterials of seafood waste, with particular reference to Southeast Asia. https://doi.org/10.32604/jrm.2022.018183
[34]. Bappenas. (2024). Draft RPJMN 2025–2029: Green Development Chapter. Ministry of National Development Planning, Indonesia. https://www.setneg.go.id/baca/index/rpjmn_2025_2029_fondasi_awal_wujudkan_visi_indonesia_emas_2045#:~:text=Presiden%20Prabowo%20Subianto%20menerbitkan%20Peraturan,pada%20tanggal%2010%20Februari%202025.
[35]. KLHK. (2025). Program Kali Bersih (Prokasih) 2025 Revitalization Strategy. Ministry of Environment and Forestry, Republic of Indonesia. https://ppid.menlhk.go.id/berita/siaran-pers/4229/klhk-dampingi-pemerintah-daerah-tuntaskan-amanat-presiden-agar-indonesia-bersih-sampah-2025
[36]. Ministry of Industry. (2025). Strategi Industri Nasional Berkelanjutan 2025-2045. Jakarta: Government of Indonesia. https://bbt.kemenperin.go.id/blog/wujudkan-visi-indonesia-emas-2045,-kemenperin-luncurkan-peta-jalan-jasa-industri-2025-%E2%80%93-2045