JPPIPA 9(2) (2023)

Jurnal Penelitian Pendidikan IPA

*Journal of Research in Science Education*

http://jppipa.unram.ac.id/index.php/jppipa/index

# Environment-based Learning Media with Green Biochemistry Approach

Muhamad Iksan[1], Frida Maryati Yusuf[2*], Dyah Pramesti Istana Ardiyati[1]

[1]Department of Biology Education, Universitas Muhammadiyah Buton, Baubau City, Indonesia
[2]Department of Biology, Universitas Negeri Gorontalo, Gorontalo City, Indonesia

Received: December 30, 2022
Revised: February 24, 2023
Accepted: February 26, 2023
Published: February 28, 2023

Corresponding Author:
Frida Maryati Yusuf
fridamaryati@ung.ac.id



DOI: 10.29303/jppipa.v9i2.2966

**Abstract:** Southeast Sulawesi is one of the provinces that has the largest mining area in Indonesia. One of the main mining commodities is nickel, which has the largest natural resource potential of around 97.3 billion tons of nickel minerals. Mining has an important role in the development of a region because it produces industrial raw materials, a source of foreign exchange, employment and increases local revenue. On the other hand, mining can cause various threats or adverse impacts in the form of environmental damage and pollution. One of the areas experiencing adverse impacts from mining is Baliara Village, Bombana Regency. This study aims to determine the formulation of efforts to overcome and prevent seawater pollution by nickel waste using the green biochemistry approach. This research was conducted in April 2022 in Baliara Village, Bombana Regency using observation, interview and literature study approaches. The results showed that there are approaches that can be used to control or reduce nickel waste, namely using the flotation-filtration method, silica-modified tofu solid waste, utilization of mangrove vegetation as nickel heavy metal phytoremediation and the establishment of corporate social responsibility (CRS) by mining companies in controlling or monitoring environmental pollution. This approach is considered very effective in controlling pollution in the aquatic environment in Baliara Village, Bombana Regency, so that it can serve as scientific input and information for relevant parties in taking actions and policies in controlling pollution in the area.

**Keywords:** Baliara village; Green biochemistry; Seawater pollution

## Introduction

Southeast Sulawesi is one of the provinces that has the largest mining area in Indonesia. Data from the Central Bureau of Statistics shows that there are 189 mining companies in Southeast Sulawesi, 128 of which are nickel mining companies, or 73 percent, spread across 11 districts and cities. Bombana Regency has 156 non-metal C mining companies with 629 workers (Badan Pusat Statistik, 2014). In addition, Southeast Sulawesi is directed to become the center of the national mining industry, considering that this region has a variety of minerals resources, large resources and high economic value (Upe et al., 2019). Nickel is the main commodity of the mining sector in Southeast Sulawesi Province. The potential of nickel mineral resources in Southeast Sulawesi Province is quite large, amounting to 97.4 billion tons spread over an area of 480 thousand hectares. In the period 2008-2013, 56.9 million tons of nickel minerals have been mined, resulting in the current available resources of 97.3 billion tons of nickel minerals (Haryadi, 2016).

Mining has an important role in development by producing industrial raw materials, absorbing labor, as a source of foreign exchange and increasing local revenue (Nazir et al., 2020). On the other hand, mining also causes various adverse impacts on the environment in the form of the risk of pollution and environmental damage (Dong et al., 2019; Ukaogo et al., 2020). There are no mining activities that do not have the potential to

**How to Cite:**
Iksan, M., Yusuf, F.M., & Ardiyati, D.P.I. (2023). Environment-based Learning Media with Green Biochemistry Approach. *Jurnal Penelitian Pendidikan IPA*, *9*(2), 796–802. https://doi.org/10.29303/jppipa.v9i2.2966

pollute and damage the environment (Fugiel et al., 2017). Environmental damage to soil structure such as soil becomes barren due to mining excavations, plants become dead and stunted. In addition, the impact of mining on water due to nickel mining is that it can cause silt and red-colored water flow due to soil erosion, and sedimentation from former excavations that drift or fall into the river or sea (Luckeneder et al., 2021).

The mining industry is one of the industries that has an impact on environmental damage both physical and social environments because in general the mining industry produces considerable waste. One of them is in the form of waste disposal and some mines produce heavy metal residues that are toxic so that they have the potential to pollute the environment (Fashola et al., 2016). The utilization of both renewable and non-renewable natural resources will not be separated from environmental damage, especially in nickel mining exploitation activities. Environmental damage caused by mining activities has had a negative impact on several districts in Southeast Sulawesi Province, one of which is Bombana Regency. Although mining activities have a positive impact on the economic aspect, environmental damage or degradation cannot be ruled out (Liu et al., 2019). As a result of this massive exploitation, environmental degradation is inevitable such as air, soil and water pollution (Ardiyansyah et al., 2019).

The mining industry has negative impacts on the environment and society, including waste disposal, toxic heavy metal residue pollution, and environmental degradation such as air, soil, and water pollution (Vardhan et al., 2019; Zhang & Wang, 2020). The negative impact of mining is evident in Bombana Regency in Southeast Sulawesi Province. Despite its positive economic impact, environmental degradation cannot be ignored.

Therefore, it is important for the mining industry to implement sustainable mining practices that minimize negative impacts on the environment and the surrounding communities. This includes proper waste management, implementing effective environmental management systems, monitoring environmental performance, and engaging with local communities to address any concerns they may have (Mungai et al., 2020). Additionally, companies should invest in research and development to improve mining technologies and processes that have lower environmental impacts. Governments also have a role to play in regulating and enforcing environmental standards in the mining industry. Overall, a collaborative effort between the industry, governments, and communities is necessary to ensure sustainable and responsible mining practices that balance economic growth and environmental protection.

Water pollution control can be done in various ways, namely mechanical chemical and biological waste control (Rajmohan et al., 2019). Mechanically, it is carried out through water pollution prevention and control technology by selecting technology that considers the characteristics of wastewater and its effluent quality standards. The selected technology is expected to be able to change the effluent quality (effluent-standard) so that it can meet the quality standards of the receiving water body (stream-standard) which can be applied optimally in order to protect the environment and provide tolerance for industrial development (Priadie, 2012). Chemically by modifying chemicals in order to degrade waste discharges effectively and efficiently.

Biologically can be done by using environmental services or organisms that have the ability to decompose waste known as bioremediation. Bioremediation is the use of microorganisms that have been selected to be grown on certain pollutants in an effort to reduce the levels of these pollutants. During the bioremediation process, enzymes produced by microorganisms modify the structure of toxic pollutants to be less complex so that they become non-toxic and hazardous metabolites.

In this case, bioremediation using selected microorganisms can be applied to decompose nickel waste and reduce its toxicity levels in seawater. This biotechnology method has been shown to be effective in reducing environmental pollution, especially in waste-contaminated environments (Khalid et al., 2021). The microorganisms can break down the toxic pollutants in nickel waste and transform them into non-toxic compounds that are less harmful to the environment (Saravanan et al., 2021). This approach is considered a green solution, as it uses natural processes to reduce pollution and minimize the negative impacts of waste on the environment. It is a sustainable solution that provides a cost-effective and environmentally friendly alternative to traditional methods of waste management and pollution control.

This paper aims to determine the mitigation and prevention of seawater pollution by nickel waste in Baliara Village, Bombana Regency using the green biochemistry approach so that it can be a reference for related parties in making policies in mitigation and prevention efforts.

The objective of this paper is to find a solution to the problem of seawater pollution caused by nickel waste in Baliara Village, Bombana Regency. The approach proposed is the green biochemistry approach, which is a sustainable and environmentally friendly method. The results of this study will serve as a reference for policy-makers and other relevant parties in their efforts to prevent and mitigate seawater pollution caused by nickel waste. The hope is that this research will provide practical and effective solutions that can be

implemented to reduce the negative impact of mining activities on the environment and local communities.

## Method

This research was conducted in April 2022 in Baliara Village, Kabaena Barat Sub-district, Bombana Regency. The approaches used in the research were observation, interview and literature study. The observation approach was used to directly observe the condition of seawater based on physical parameters. The interview approach was conducted to find out information related to seawater pollution data due to nickel waste by the surrounding community using a research questionnaire, while the literature study was conducted by searching for relevant literature as a solution for the prevention and control of seawater pollution in Baliara Village, Bombana Regency, Southeast Sulawesi Province.

## Result and Discussion

Environmental pollution is the entry or inclusion of living things, substances, energy, and/or other components into the environment by human activities so that it exceeds the established environmental quality standards. According to (Sujarwo & Caneva, 2015), pollution is caused by 4 (four) things, namely: (a) The existence of pollution due to the greater speed of production of a substance than the speed of its use or degradation in physical chemistry. (b) The cause of pollution due to biological processes that form or concentrate certain polluting substances, types of microbes, for example, can form toxic substances such as tofu bongkrek and alpha-toxlin in some human or livestock foodstuffs. Fish can concentrate pollutants. Processes through the food chain may also occur; (c) Based on non-biological physico-chemical processes; (d). The occurrence of accidents that can release certain substances into the environment.

Based on direct observation, the condition of seawater in Baliara Village, Bombana Regency, has changed, such as brown seawater, the smell of seawater that is not like seawater in general, and the presence of thick silt at the bottom of the water. Based on the results of interviews with the surrounding community, the condition of sea water in Baliara Village has a red color, silt with a thickness of 20 cm and the water feels itchy when exposed to the skin. The quality standard value based on KLH No. 51 of 2004 (Rinawati et al., 2016), with a maximum limit of dissolved metal content Ni of 0.05 mg/L for marine biota and marine tourism 0.075 mg/L. Based on the integrated monitoring and evaluation of the Environmental Agency (DLH) of Bombana Regency, it was found that the nickel mining company did not make a settling pond in the bravo block in the new opening mining so that the waste water from production was not properly filtered.

Controlling seawater pollution by nickel waste can be done using a green biochemistry approach. Green biochemistry is an approach to environmental pollution control by focusing on the principles of chemistry, biology and the application of technology in it so as to prevent environmental pollution caused by toxic and hazardous chemical processes and products. Aspects of green biochemistry are minimization of hazardous substances, use of reaction catalysts and chemical processes, use of non-toxic reagents, use of renewable resources, improvement of atomic efficiency, use of environmentally friendly and recyclable solvents. Green biochemistry aims to develop chemical and biological processes and chemical products that are environmentally friendly and in accordance with sustainable development (Susanti, 2022). Based on the results of literature searches and literature relevant to the problem, it was found that the green biochemistry approach can effectively control seawater pollution in Baliara Village, Bombana Regency, including nickel waste management using the flotation-filtration method, waste management with silica-modified tofu waste, utilization of mangroves as heavy metal absorbers and forming a Corporate Social Responsibility (CSR) program for the environment.

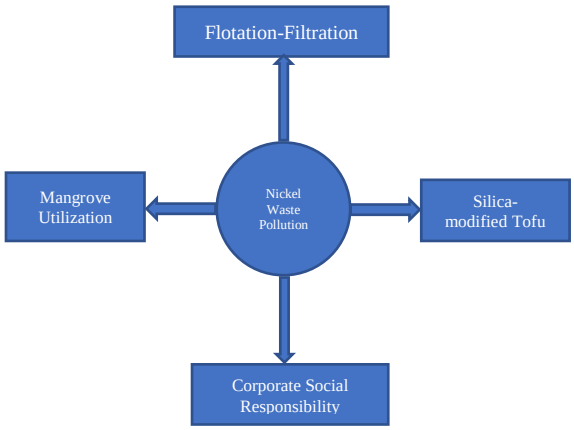


**Figure 1**. Nickel waste control with green biochemistry approach

*Flotation-Filtration Method*

Flotation is a separation of a substance from other substances in a liquid / solution based on differences in the surface properties of the substances to be separated, while filtration is a process of separating solids from the fluid (liquid or gas) that underlies it using a porous medium or other porous material to remove as much suspended and colloidal fine solids as possible (Ying &

Park, 2018). Liquid waste containing heavy metals such as nickel. Particles that cannot be separated by the flotation process can be separated through the filtration process. The series of flotation-filtration equipment can be seen in the Figure 2.

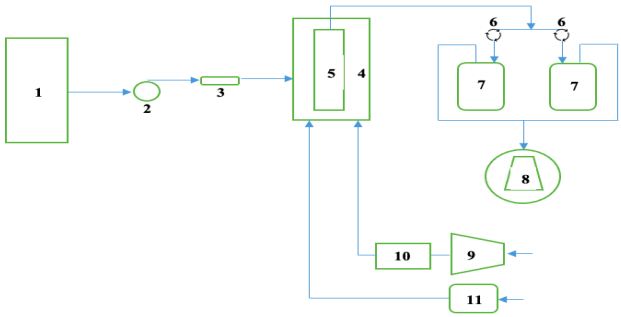


**Figure 2**. Method design of flotation-filtration device

**Notes:**

| | |
|---|---|
| 1.Mixing tank | 7. Permeate tank |
| 2.Water pump | 8. Vacuum pump |
| 3.Water flowmeter | 9. Compressor |
| 4.Flotation-filtration tank | 10. Air flowmeter |
| 5.Ceramic membrane | 11. Ozonator |
| 6.Valve | |

The above tools can be used as flotation, filtration or flotation-filtration tools. To run the flotation process, tools such as ceramic membranes, permeate tanks and vacuum pumps are not used or functioned, while in the filtration process the compressor and ozonator are not activated and all tools will be used when the flotation-filtration process takes place. The flotation-filtration process can treat heavy metal waste such as Ni, Fe and Cu continuously for 10 minutes. The use of this tool is done by flowing the waste heavy metal waste mixture into the flotation-filtration tank, then activating the vacuum pump, compressor, and ozonator simultaneously (the water pump remains active). The feed flow rate was adjusted to the permeate pump flow rate and air flow rate of 100 L/h. The flotation-filtration method is a combination of flotation and filtration processes that aims to separate solid or liquid particles from a liquid phase waste. The advantages of using flotation-filtration include high selectivity, operating at ambient conditions, no phase change in the removal process, small and simple operating units (Pereao et al., 2017). This method is designed into a tool for separating hazardous waste by 94.73%, 87.92% and 88.105% (Asep et al., 2008).

The use of this tool using flotation and filtration methods requires a fairly expensive cost so that it can be the responsibility of companies engaged in mining. This tool can also be an alternative solution for companies that have problematic WWTPs so as to reduce pollution of water areas due to heavy metal waste that has the potential to pollute the environment when disposed of on land or in waters. In addition, this method is very effective in separating nickel waste so it is highly recommended to be further developed in commercial use by companies. To be applied commercially, it can be strengthened by government regulations or related regulations so that it can become an alternative tool in removing heavy metals, especially nickel.

*Use of silica-modified tofu solid waste*

Silica is a series of minerals composed of one silicon atom (Si) and two oxygen atoms (O2). Silica naturally occurs in crystalline and amorphous forms. Crystalline silica is found in 3 main forms, namely quartz, tridymite and cristobalite. Meanwhile, amorphous structures can be found in the form of opal, flint, silica glass, diatomaceous earth and vitreous silica (Pavan & Fubini, 2017). Silica functions as an adsorbent that has a pore geometry structure, chemical properties on the surface can be modified so that it can separate molecules well and the processing process is simple through sol-gel processing (Elma et al., 2012).

The tofu industry in its processing process produces waste in the form of liquid or solid waste that can be utilized as an adsorbent or heavy metal absorbent media. This can be explained because the waste contains proteins that can bind heavy metals (Gisi et al., 2016). One method of controlling heavy metal waste is the adsorption method through modification of tofu waste with silica. Adsorption is one of the efficient methods used to remove heavy metals because it does not require complicated equipment and is quite easy to implement. The addition of silica to tofu waste aims to increase its ability to absorb heavy metals, have better mechanical strength, and be resistant to biological degradation.

Tofu waste is the residue of the tofu making process which contains hydroxyl groups, amino groups, and other functional groups in large quantities, especially in the polypeptide chain. These groups can be utilized to adsorb various heavy metal ions because they form good metal ion chelate complexes so they have the potential to be utilized as bio sorbents to remove various heavy metal ions from the aquatic environment (D. Liu et al., 2013). One of the most abundant functional groups in tofu is amino acids which can form ion swatters that can also bind heavy metal ions (Anggraini & Dinata, 2020).

Although tofu waste is a potential material for adsorption of heavy metal ions, as a bio adsorbent it has several disadvantages including weak mechanical properties, not resistant to high temperatures, and easily attacked by bacteria and fungi. For this reason, further modification is needed with the aim of improving some of these weaknesses with the aim of obtaining stronger mechanical properties, resistance to bacterial and fungal attacks, resistance to acids, and resistance to temperatures in the 30-60 ℃ range. One of the materials

that can be used to modify tofu waste (especially solid tofu waste) and has also never been researched is utilizing inorganic silica material made from a precursor solution of Na2SO3 with concentrated HCl, ultimately producing silica gel.

Silica gel is an inorganic material that can be used as a host to modify adsorbents from tofu waste into new adsorbent materials through the immobilization mechanism of active groups (in this case amide groups) from solid tofu waste on the surface of the active groups of silica gel. The active groups in silica are silanol groups (Si-OH) and siloxane groups (Si-O-Si) (Jal et al., 2004). In addition to amide groups, silanol groups and siloxane groups can also interact with other functional groups.

How to make silica-modified tofu solid waste, namely solid tofu waste that is still wet, is dried in an oven at 40oC for 8 hours to reduce water content. The dried solid tofu waste is then crushed with a mortar to obtain a powder form. Solid tofu waste that has been in powder form is sieved to get adsorbent raw materials with a 100-mesh sieve. Extra pure Na2SiO3 solution was placed in a plastic container, then concentrated HCl was added by slowly dripping while stirring to form a gel. Then solid tofu waste adsorbent that has been finely mixed into the gel formed while continuing to stir. The mixture of gel with solid tofu waste that has been formed is then oven dried at 40 OC for 2 hours. The results of silica-modified tofu waste can be seen in Figure 3.

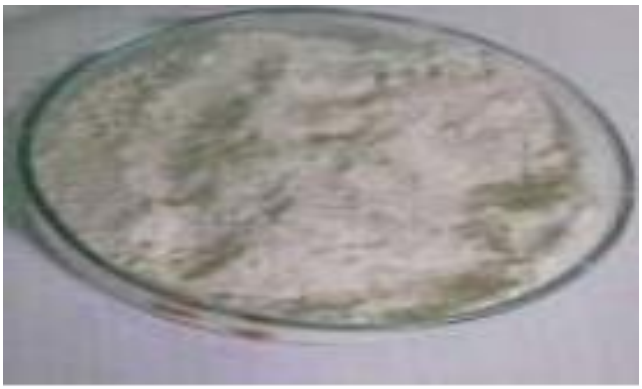

**Figure 3**. Modification results of silica-modified tofu solid waste

The way to use this method is by mixing the modified tofu solid waste and silica with nickel waste in a modified place such as a WWTP so that it can accommodate more waste before being disposed of in the environment. The absorption of heavy metal nickel using tofu solid waste modified with silica reached 90% (Ng et al., 2021). This is a very important prospect considering that this method is environmentally friendly and does not require expensive costs. In addition, the use of this method also needs to be developed and researched by companies engaged in mining so that they can find innovations in increasing waste absorption using materials that are cheap and do not pollute the environment. The application of adequate technology can also improve the development of nickel waste control methods using silica-modified tofu solid waste.

*Utilization of mangroves as a sorbent of heavy metals Nickel (Ni)*

Bioremediation is the utilization of biological processes to control pollution or pollutants in the field of environmental biotechnology. The use of biodegradative processes to remove or detoxify pollutants (usually soil, water, and sediment contaminants) that pollute the environment and endanger public health is referred to as remediation (Sanadi et al., 2018). One of the plants that has the ability to absorb heavy metal pollutants is mangrove plants. Mangroves are included in hyperregular plants because they function as natural bioremediation agents because mangroves can naturally absorb heavy metal content in nature, which is referred to as biosorption. These mangrove trees try to cope with other harmful elements by reducing the toxic effect through dilution, especially by storing large amounts of water to dilute the concentration of heavy metals in body tissues thereby reducing their toxicity (Utami et al., 2018). In addition, mangroves store harmful heavy metal compounds in aged tissues such as old leaves and easily exfoliated bark, thereby reducing the concentration of heavy metals in the body.

Based on the observation, the coastal area of Baliara Village has muddy beach characteristics and there are several mangrove species that are still remaining and still survive. The results of interviews with the surrounding community that, in the past the baliara coastline was overgrown with mangrove vegetation but over time the vegetation decreased due to excessive utilization in the form of mangrove wood exploitation so that mangrove vegetation was damaged and lost. The ability of mangrove forests to absorb heavy metal waste so that mining companies must form corporate social responsibility (CSR) to replant mangrove vegetation, especially species of Avicennia marina, Rhizophora mucronata, and Bruguiera gymnorrhiza can absorb heavy metals effectively. However, Avicennia species are thought to have higher resistance to some metals than other mangrove species (Utami et al., 2018). CSR activities can involve all elements of society and environmentalists or the government in the process of replanting damaged vegetation so that in the future the waste that enters the aquatic environment can be absorbed directly by mangrove vegetation. In addition to absorbing heavy metal waste, mangrove forests can provide other benefits such as protecting coastal

abrasion, fish spawning grounds, carbon storage and a place to live for various types of fish.

CSR is also responsible for the problem of environmental wastes making water toxic and killing organisms in the water. There are two ways to deal with pollution, namely non-technical and technical countermeasures. Non-technical countermeasures are efforts to reduce environmental pollution by creating laws that can plan, regulate, and supervise all forms of industrial activities so that no pollution occurs while technical countermeasures by managing waste or adding tools that can reduce pollution. In addition, CSR can also periodically control the potential for pollution caused by company activities so as to minimize the emergence of various pollution both in soil, water and air.

## Conclusion

Based on the explanation above, efforts to overcome and prevent seawater pollution by nickel waste in Baliara Village, Bombana Regency can be done with a green biochemistry approach, namely controlling nickel waste using the flotation-filtration method, silica-modified tofu solid waste, utilization of mangrove plants as nickel heavy metal absorbents and the formation of corporate social responsibility (CSR) by nickel mining companies. It is hoped that a more in-depth literature review can be carried out related to heavy metal waste control so as to find the best method formulation in solving environmental pollution problems in water areas and the use of technology in supporting methods that have been developed so that they can effectively and efficiently reduce environmental pollution.

## References


Anggraini, L., & Dinata, M. (2020). Akumulasi Logam Berat Pada Batang Eichhornia Crassipes Solms Pada Variasi Media Penyaring Selama Remediasi Air Lindi. *Bio-Lectura*, *7*(1), 77–88. https://doi.org/10.31849/bl.v7i1.4013

Ardiyansyah, P., Wasis, B., & Hilwan, I. (2019). Karakteristik Vegetasi di Hutan Alam Dataran Rendah, Hutan Tanaman, dan Lahan Pasca Tambang Nikel di Kabupaten Bombana. *Journal of Tropical Silviculture*, *10*(3), 140–145. https://doi.org/10.29244/j-siltrop.10.3.140-145

Asep, E. K., Jinap, S., Tan, T. J., Russly, A. R., Harcharan, S., & Nazimah, S. A. H. (2008). The effects of particle size, fermentation and roasting of cocoa nibs on supercritical fluid extraction of cocoa butter. *Journal of Food Engineering*, *85*(3), 450–458. https://doi.org/10.1016/j.jfoodeng.2007.08.008

Badan Pusat Statistik. (2014). *Kecamatan Bombana Dalam Angka*. Diakses Pada Tanggal 25 April 2022 Melalui Https://Bombanakab.Bps.Go.Id/.

De Gisi, S., Lofrano, G., Grassi, M., & Notarnicola, M. (2016). Characteristics and adsorption capacities of low-cost sorbents for wastewater treatment: A review. *Sustainable Materials and Technologies*, *9*, 10–40. https://doi.org/10.1016/j.susmat.2016.06.002

Dong, L., Tong, X., Li, X., Zhou, J., Wang, S., & Liu, B. (2019). Some developments and new insights of environmental problems and deep mining strategy for cleaner production in mines. *Journal of Cleaner Production*, *210*, 1562–1578. https://doi.org/10.1016/j.jclepro.2018.10.291

Elma, M., Yacou, C., Wang, D. K., Smart, S., & Diniz da Costa, J. C. (2012). Microporous silica based membranes for desalination. *Water (Switzerland)*, *4*(3), 629–649. https://doi.org/10.3390/w4030629

Fashola, M. O., Ngole-Jeme, V. M., & Babalola, O. O. (2016). Heavy metal pollution from gold mines: Environmental effects and bacterial strategies for resistance. *International Journal of Environmental Research and Public Health*, *13*(11), 1047. https://doi.org/10.3390/ijerph13111047

Fugiel, A., Burchart-Korol, D., Czaplicka-Kolarz, K., & Smoliński, A. (2017). Environmental impact and damage categories caused by air pollution emissions from mining and quarrying sectors of European countries. *Journal of Cleaner Production*, *143*, 159–168. https://doi.org/10.1016/j.jclepro.2016.12.136

Haryadi, H. (2016). Analisis Dampak Pembangunan Smelter Nikel Terhadap Perekonomian Daerah Di Provinsi Sulawesi Tenggara. *Buletin Sumber Daya Geologi*, *11*(1), 25–39. https://doi.org/10.47599/bsdg.v11i1.8

Jal, P. K., Patel, S., & Mishra, B. K. (2004). Chemical modification of silica surface by immobilization of functional groups for extractive concentration of metal ions. *Talanta*, *62*(5), 1005–1028. https://doi.org/10.1016/j.talanta.2003.10.028

Khalid, F., Hashmi, M. Z., Jamil, N., Qadir, A., & Ali, M. I. (2021). Microbial and enzymatic degradation of PCBs from e-waste-contaminated sites: a review. *Environmental Science and Pollution Research*, *28*(9), 10474–10487. https://doi.org/10.1007/s11356-020-11996-2

Liu, D., Li, Z., Li, W., Zhong, Z., Xu, J., Ren, J., & Ma, Z. (2013). Adsorption behavior of heavy metal ions from aqueous solution by soy protein hollow microspheres. *Industrial and Engineering Chemistry Research*, *52*(32), 11036–11044. https://doi.org/10.1021/ie401092f

Liu, W., Agusdinata, D. B., & Myint, S. W. (2019). Spatiotemporal patterns of lithium mining and

environmental degradation in the Atacama Salt Flat, Chile. *International Journal of Applied Earth Observation and Geoinformation*, *80*, 145–156. https://doi.org/10.1016/j.jag.2019.04.016

Luckeneder, S., Giljum, S., Schaffartzik, A., Maus, V., & Tost, M. (2021). Surge in global metal mining threatens vulnerable ecosystems. *Global Environmental Change*, *69*, 102303. https://doi.org/10.1016/j.gloenvcha.2021.102303

Mungai, E. M., Ndiritu, S. W., & Rajwani, T. (2020). Do voluntary environmental management systems improve environmental performance? Evidence from waste management by Kenyan firms. *Journal of Cleaner Production*, *265*, 121636. https://doi.org/10.1016/j.jclepro.2020.121636

Nazir, M., Murdifin, I., Putra, A. H. P. K., Hamzah, N., & Murfat, M. Z. (2020). Analysis of economic development based on environment resources in the mining sector. *Journal of Asian Finance, Economics and Business*, *7*(6), 133–143. https://doi.org/10.13106/JAFEB.2020.VOL7.NO6.133

Ng, H. K. M., Lim, G. K., & Leo, C. P. (2021). Comparison between hydrothermal and microwave-assisted synthesis of carbon dots from biowaste and chemical for heavy metal detection: A review. *Microchemical Journal*, *165*, 106116. https://doi.org/10.1016/j.microc.2021.106116

Pavan, C., & Fubini, B. (2017). Unveiling the variability of "quartz hazard" in light of recent toxicological findings. *Chemical Research in Toxicology*, *30*(1), 469–485. https://doi.org/10.1021/acs.chemrestox.6b00409

Pereao, O. K., Bode-Aluko, C., Ndayambaje, G., Fatoba, O., & Petrik, L. F. (2017). Electrospinning: Polymer Nanofibre Adsorbent Applications for Metal Ion Removal. *Journal of Polymers and the Environment*, *25*(4), 1175–1189. https://doi.org/10.1007/s10924-016-0896-y

Priadie, B. (2012). Teknik Bioremediasi Sebagai Alternatif Dalam Upaya Pengendalian Pencemaran Air. *Jurnal Ilmu Lingkungan*, *10*(1), 38. https://doi.org/10.14710/jil.10.1.38-48

Rajmohan, K. V. S., Ramya, C., Raja Viswanathan, M., & Varjani, S. (2019). Plastic pollutants: effective waste management for pollution control and abatement. *Current Opinion in Environmental Science and Health*, *12*, 72–84. https://doi.org/10.1016/j.coesh.2019.08.006

Rinawati, Hidayat, D., Suprianto, R., & Dewi, P. S. (2016). Penentuan Kandungan Zat Padat (Total Dissolve Solid Dan Total Suspended Solid)Di Perairan Teluk Lampung. *Analit: Analytical and Environmental Chemistry*, *1*(1), 36–46. https://jurnal.fmipa.unila.ac.id/analit/article/view/1236

Sanadi, T., Schaduw, J., Tilaar, S., Mantiri, D., Bara, R., & Pelle, W. (2018). Analisis logam berat timbal (Pb) pada akar mangrove di Desa Bahowo dan Desa Talawaan Bajo Kecamatan Tongkaina. *Jurnal Pesisir Dan Laut Tropis*, *6*(2), 9. https://doi.org/10.35800/jplt.6.2.2018.21382

Saravanan, A., Kumar, P. S., Vo, D. V. N., Jeevanantham, S., Karishma, S., & Yaashikaa, P. R. (2021). A review on catalytic-enzyme degradation of toxic environmental pollutants: Microbial enzymes. *Journal of Hazardous Materials*, *419*, 126451. https://doi.org/10.1016/j.jhazmat.2021.126451

Sujarwo, W., & Caneva, G. (2015). Ethnobotanical study of cultivated plants in home gardens of traditional villages in Bali (Indonesia). *Human Ecology*, *43*(5), 769–778. https://doi.org/10.1007/s10745-015-9775-8

Susanti, L. Y. (2022). Pengembangan Modul Praktikum berbasis Green Chemistry untuk Menanamkan Karakter Peduli Lingkungan pada Calon Guru IPA. *Jurnal Pendidikan Mipa*, *12*(3), 798–807. https://doi.org/10.37630/jpm.v12i3.657

Ukaogo, P. O., Ewuzie, U., & Onwuka, C. V. (2020). Environmental pollution: Causes, effects, and the remedies. In *Microorganisms for Sustainable Environment and Health* (pp. 419–429). Elsevier. https://doi.org/10.1016/B978-0-12-819001-2.00021-8

Upe, A., Salman, D., & Agustang, A. (2019). The effects of the exploitation of natural resources towards risk society construction in Southeast Sulawesi Province, Indonesia. *Journal of Degraded and Mining Lands Management*, *6*(2), 1587–1594. https://doi.org/10.15243/jdmlm.2019.062.1587

Utami, R., Rismawati, W., & Sapanli, K. (2018). Pemanfaatan Mangrove Untuk Mengurangi Logam Berat Di Perairan. *Prosiding Seminar Nasional Hari Air Dunia*, *2*(1), 141–153.

Vardhan, K. H., Kumar, P. S., & Panda, R. C. (2019). A review on heavy metal pollution, toxicity and remedial measures: Current trends and future perspectives. *Journal of Molecular Liquids*, *290*, 111197. https://doi.org/10.1016/j.molliq.2019.111197

Ying, Y., & Park, D. (2018). *Pemisahan Emulsi Dengan Penggumpalan Deterjen Memakai Metoda Flotasi Dan Filtrasi* (pp. 6–7). Institut Teknologi Sepuluh Nopember.

Zhang, Q., & Wang, C. (2020). Natural and Human Factors Affect the Distribution of Soil Heavy Metal Pollution: a Review. *Water, Air, and Soil Pollution*, *231*(7), 1–13. https://doi.org/10.1007/s11270-020-04728-2