http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 11 No 1 2026

RESEARCH ARTICLE

Analysis of Content, Source and Impact of Heavy Metals in Sombori Island, Central Sulawesi, Indonesia

Hasria Hasria[1,*], Ida Usman[2], Karim Saeri[1], Nasaruddin[3], Sara Septiana[4], Mohammad Rais[5] Harisma Harisma[1], Silo Musrajab[1]

[1] *Department of Geological Engineering, Halu Oleo University, Kendari, Indonesia*
[2] *Department of Physics, Halu Oleo University, Kendari, Indonesia*
[3] *Department of Biology, Halu Oleo University, Kendari, Indonesia*
[4] *Department of Geological Engineering, University of Southeast Sulawesi, Kendari, Indonesia*
[5] *Department of Fisheries Resources Utilitation, Muhammadiyah University of Kendari, Indonesia*

* Corresponding author : hasriageologi@gmail.com
Tel.: +62 852-4158-7853
Received: Jul 9, 2025; Accepted: Mar 13, 2026.
DOI: 10.25299/jgeet.2026.11.1.23856

Abstract

A study was conducted on Sombori Island, Central Sulawesi. The purpose of this study was to determine the content of heavy metals and the origin of contamination and the impact of heavy metal contamination. Seawater samples totaling 30 stations were analyzed in the form of total suspended solids (TSS), pH, salinity and heavy metal content of hexavalent chromium (Cr^{6+}) and nickel (Ni) using Atomic Absorption Spectrometry (AAS) analysis. The heavy metals chromium (Cr) and nickel in the sediment were analyzed using flame Atomic Absorption Spectrometry (AAS). The results of the study showed that heavy metals in seawater in the form of Ni are still safe for the marine ecosystem of the research area. However, the heavy metal Cr^{6+} has contaminated several marine waters stations because it has exceeded the established quality standards so that it can have a negative impact on the marine ecosystem including humans through the food chain. The content of heavy metal Cr in marine sediments has not passed the established sediment quality standards. However, for heavy metal Ni in sediment, it has exceeded the established sediment quality standards so that it has had a negative impact on the marine ecosystem that lives and feeds around/on the sediment including humans through the food chain. Sources of contamination of heavy metals in water and sediment are from the weathering of ultramafic rocks containing heavy metals, mining activities, shipping activities using fossil fuels, the use of ship paint containing heavy metals, solid waste from ships containing heavy metals and domestic waste.

Keywords: Heavy metal, Impact, Hexavalent chromium, Chromium, Nickel, Sombori Island

1. Introduction

Indonesia is an archipelago with five large islands, namely Kalimantan, Sumatra, Papua, Java and Sulawesi. These islands have their own characteristics, especially Sulawesi Island which has a complex tectonostratigraphic evolution. (Maulana et al., 2020) and a unique shape resembling the letter K (**Figure 1**). This island was formed as a result of the collision of three of the world's tectonic plates, namely the Indo-Australian plate, the Pacific plate and the Eurasian plate (Hamilton, 1979). Sulawesi Island is part of a highly active and diverse tectonic complex, formed by plate interaction. This tectonic activity resulted in the Ophiolite Complex, which was uplifted to the surface as part of the accreted oceanic crust embedded in the plate interface. Extensive exposures of ultramafic rocks, one of the rocks of this Ophiolite Complex, created a nickel-rich basement rock that served as the primary source rock for lateritization under intense tropical climates (Ahmad, 2001; Elias, 2002; Kadarusman et al., 2004). This condition also causes Sulawesi Island has various potential mineral resources as a result of the interaction of these plates, such as asphalt, coal, orogenic gold deposits, cobalt, manganese, Fe laterite, chromite, nickel laterite and so on (Leeuwen and Pieters, 2011; Hasria et al., 2019a; 2019b; 2021a; 2021b; 2021c; 2024a; 2024b; Hasria and Septiana, 2024).

Geologically, nickel laterite can be found in the East Sulawesi Ophiolite Belt in ultramafic rocks. The ophiolite complex is a collection of oceanic crust rocks that have experienced emplacement during the process of convergent plate movement (Permana and Surono, 2013). Nickel laterite is a deposit formed as a result of a very intensive weathering process on ultramafic rocks containing nickel such as peridotite, dunite and serpentinite in subtropical to tropical climates over a long geological period.

Sombori Island is located in Morowali Regency, Central Sulawesi Province and is included in the Lasusua-Kendari Geological Map Sheet, Central Sulawesi (Rusmana et al., 1993). Some areas have lithology in the form of ultramafic rocks that host laterite nickel deposits so that there are several nickel mining companies. The existence of these companies can be a source of pollution for several heavy metals associated with nickel. This is because nickel mining activities involve stripping of soil and rock layers (overburden), as well as moving mining materials.

As a result, when it rains, it will be easily eroded, then these soil particles will be transported to rivers/seas which can cause increased contamination of heavy metals in waters that can be toxic if they exceed the established quality standards. The toxicity of heavy metals in the marine environment has a high potential risk for a number of flora and fauna including humans, through the food chain.

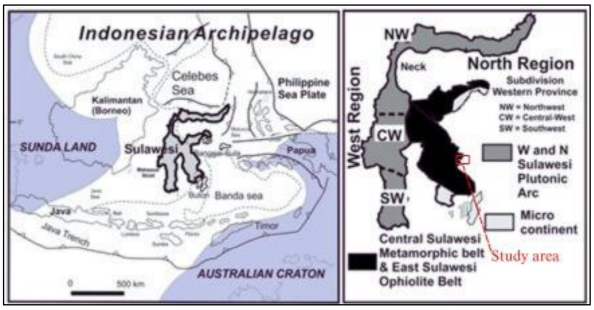

Fig 1. Tectonic setting and simplified regional geology of Sulawesi (modified from Maulana et al., 2020).

The aim of this research is to determine the heavy metal content and origin of contamination as well as the impact of heavy metal contamination in the form of hexavalent chromium (Cr^{6+}) and nickel (Ni) in seawater and chromium (Cr) and Ni in sediment.

2. Research Methodology

The location of water and sediment sampling was carried out in the sea waters around Sombori Island, Morowali Regency, Central Sulawesi. The number of sampling stations was 30 stations (**Figure 2**) consisting of 30 water samples and 30 sediment samples. Water samples were taken directly below the water surface with varying depths ranging from 3 to 9 meters with an average distance of 5 cm from the seabed. Then the water was put into a sample bottle and the bottle was given a station code which was then put into a coolbox. Meanwhile, sediment sampling used a grab sampler which was then put into a sample bag and given a station code then put into a coolbox.

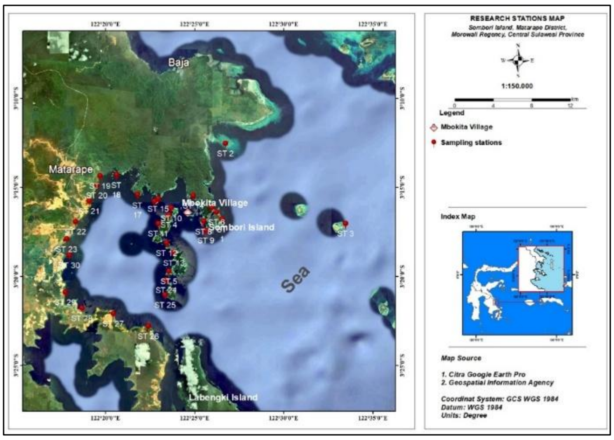

Fig 2. Map of research area stations (modified from Rusmana et al., 1993).

Level Seawater and sediment samples were analyzed for their heavy metal content at the Biomolecular and Environmental Laboratory Unit of the Faculty of Mathematics and Natural Sciences, Halu Oleo University, Kendari. Seawater samples were analyzed for total suspended solids (TSS), pH, salinity and heavy metal content of Cr6+ and Ni using Atomic Absorption Spectrometry (AAS) analysis. Meanwhile, heavy metals in sediment were analyzed using flame Atomic Absorption Spectrometry (AAS). Determination of seawater quality standards for TSS, pH and salinity as well as heavy metal content in the form of Cr6+ and Ni is based on Government Regulation of the Republic of Indonesia Number 22 of 2021 on the Implementation of Environmental Protection and Management. The determination of marine sediment quality standards for heavy metal content Cr is based on marine sediment quality standards according to Department of Ecology State of Washington, 2013 chapter WAC 173-204-320, while the heavy metal content Ni is based on Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario, 1993.

3. Result and Discussion

Results and discussion of the content and sources and impacts of heavy metal contamination including total suspended solids (TSS), pH, salinity, hexavalent chromium (Cr^{6+}) and nickel (Ni) in seawater, as well as chromium (Cr) and nickel in sediments

3.1 Content, Sources and Impacts of Heavy Metal Contamination in Seawater

A. Total Suspended Solids (TSS) Suspended Solids (TSS)

The results of TSS measurements in the research area showed varying values ranging from 40-84 mg/L (**Table 2**). The standard for TSS quality in seawater is based on Government Regulation of the Republic of Indonesia Number 22 of 2021 is 20 mg/L for coral and seagrass; and 80 mg/L for mangrove. This shows that TSS at all stations in the research area has exceeded seawater quality standards. According to (Bilotta and Brazier, 2008) that suspended solids refer to the concentration of inorganic and organic materials, which are suspended in the water column due to turbulence. The addition of suspended solids in a water body, can increase turbidity, thereby limiting the penetration of sunlight into the water.

The sources of suspended solids are indicated to come from natural and anthropogenic processes. Natural sources include weathering of rocks which are then eroded by wind or rain and carry soil and sediment particles into the sea; the presence of high waves and strong ocean currents that can stir sediment from the seabed causing particles to become suspended and rise into the water column; and tidal changes that can cause the lifting of mud or sand from the seabed to the surface. Anthropogenic sources are indicated to come from mining activities, shipping activities that use fossil fuels, domestic waste and so on.

The decrease in sunlight penetration will have an impact on the photosynthesis process of phytoplankton and aquatic plants which will not take place perfectly. If TSS has a value of 40 to <100 mg/L, it will have an impact on the decrease in primary productivity by 13-50% in macrophyte and algae organisms due to the blocking of light penetration into the water, thus disrupting the photosynthesis process. (Bilotta and Brazier, 2008). However, this concentration has not harmed other marine biota, but only reduces the amount of productivity of certain marine organisms.

B. pH

The results of pH measurements in the research area varied and ranged between 8.12-8.45 (Table 2). Based on Government Regulation of the Republic of Indonesia Number 22 of 2021 that the standard pH quality for marine biota is 7-8.5. This shows that the pH of seawater in the research area is still within the tolerance limit according to the standard quality of seawater and has not endangered the marine biota ecosystem.

C. Salinity

The results of seawater salinity measurements in the research area vary and range between 30-31‰ (Table 2).

Referring to the seawater salinity quality standards, especially for marine biota according to Government Regulation of the Republic of Indonesia Number 22 of 2021 is 33-34‰, then the research area has a low salinity level. A decrease in salinity can cause an increase in the accumulation of heavy metals. (Laing et al., 2007; Syaifudin et al., 2025) The low salinity value can be influenced by the movement of water masses caused by wind or mixing due to sea waves and mixing with fresh water carried by river flows. The low salinity of seawater in the research area is also influenced by several factors, namely river flow, water circulation patterns, rainfall and evaporation.

D. Hexavalent Chromium (Cr^{6+})

The content of hexavalent chromium Cr^{6+} in the research area ranges from 0.0011-0.0514 mg/L (**Table 2**). The standard value of Cr^{6+} quality in seawater is based on Government Regulation of the Republic of Indonesia Number 22 of 2021 is 0.050 mg/L. This shows that several stations in the research area have Cr6+ content that exceeds the established quality standard (**Figure 3**). There are 15 stations in the research area that exceed the quality standard, namely stations ST 1, 2, 3, 7, 8, 10, 11, 12, 13, 14, 15, 16, 18, 20 and ST 21. Based on the distribution of existing stations, it shows that only 2 stations are polluted near the mining area, namely ST 21 and ST 22. The other 13 polluted stations are located quite far from the mining area (**Figure 4**).

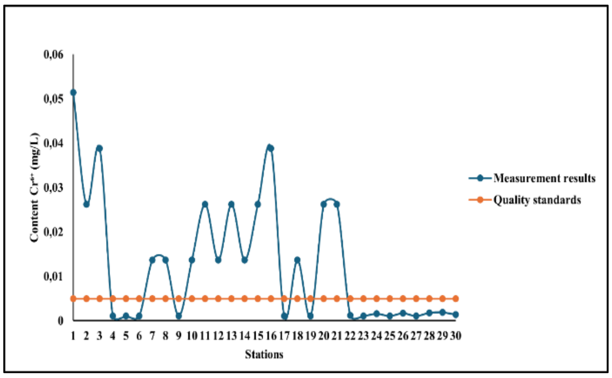

Fig 3. Comparison graph between the Cr6+ content from the measurement results (blue) and the quality standard (orange).

There are 15 stations in the research area that exceed the quality standard, namely stations ST 1, 2, 3, 7, 8, 10, 11, 12, 13, 14, 15, 16, 18, 20 and ST 21. Based on the distribution of existing stations, it shows that only 2 stations are polluted near the mining area, namely ST 21 and ST 22. The other 13 polluted stations are located quite far from the mining area (**Figure 4**).

Based on the results obtained, it shows that the high Cr^{6+} contamination in the research area is indicated not only to originate from nickel mining activities but is also influenced by other factors. (Khare et al., 2018) stated that the source of hexavalent chromium is commonly found in industrial waste from electroplating, tanning, cement, mining activities, textiles, domestic waste, solid waste, fertilizers and photography. Referring to the above, it is indicated that the source of pollution from Cr^{6+} metal in the research area is through natural and anthropogenic sources. Natural sources come from the weathering process of ultramafic rocks containing heavy metal Cr^{6+} which then undergo rosion and transportation to the sea and enter sea waters.

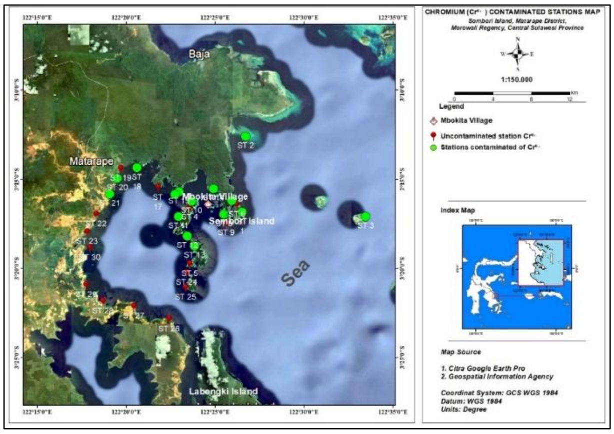

Fig 4. Distribution map of stations experiencing Cr^{6+} heavy metal contamination (green) and those not experiencing Cr^{6+} contamination (red) (modified from Rusmana et al., 1993).

Anthropogenic sources can come from mining activities, shipping activities that pass through the research area which leave waste containing heavy metal Cr^{6+} and domestic waste because in some sampling areas, there are residential areas.

Hexavalent chromium has persistent, bioaccumulative, toxic, and non-biodegradable properties in the environment, and accumulates in the human body through the food chain. Hexavalent chromium is produced from the natural oxidation process of Cr^{3+} carrier minerals. This heavy metal is easily soluble and very mobile compared to the trivalent form (Cr^{3+}). Cr^{6+} is highly carcinogenic and is known to be 100-1000 times more toxic than Cr^{3+} (trivalent chromium). The impact of this heavy metal if above the standard quality standards can cause lung cancer; stomach, nasal cavity, larynx and paranasal sinuses (Linos et al., 2011). Hexavalent chromium Cr (VI) is a class 1 carcinogen classified by multiple complex mechanisms that trigger the development of cancer (DesMarias and Costa, 2019).

E. Nickel

The nickel (Ni) content in the research area ranges from 0.014-0.0274 mg/L. The nickel quality standard is based on Government Regulation of the Republic of Indonesia Number 22 of 2021 is 0.005 mg/L Based on this, the research area has not been contaminated by nickel heavy metals. This indicates that the aquatic ecosystem of the research area is still safe from nickel heavy metals. The low Ni content value is indicated because some of the Ni that enters the marine environment is carried to the open sea due to the influence of the tides and then carried by the current and then deposited in the sediment.

3.2. Content, Sources and Impacts of Heavy Metal Contamination in Sediments

A. Chromium

The measurement results show that the heavy metal Cr in the sediment (**Table 3**), based on marine sediment quality standards according to Department of Ecology State of Washington, 2013 chapter WAC 173-204-320, then the presence of heavy metals is still in accordance with the established standards and has not contaminated marine sediments. This means that marine biota that live and feed around/on sediments or the bottom of the waters are still safe and have not been adversely affected by the presence of heavy metals Cr so that they can still maintain a healthy and diverse population.

Table 2. Results of measurements of total suspended solids (TSS), pH, salinity and heavy metal content of Cr^{6+} and Ni in seawater.

No	Station	Total Suspended Solids (TSS) (mg/L)	pH (Degree of Acidity)	Salinity (‰)	Heavy metal (mg/L)	
					Nickel (Ni)	Hexavalent chromium (Cr^{6+})
1	ST 1	52	8.12	31	0.0101	0.0514
2	ST 2	58	8.33	32	0.0245	0.0262
3	ST 3	40	8.37	31	0.0158	0.0388
4	ST 4	60	8.43	31	0.0101	0.0011
5	ST 5	58	8.40	31	0.0101	0.0011
6	ST 6	78	8.31	32	0.0072	0.0011
7	ST 7	62	8.32	31	0.0158	0.0137
8	ST 8	54	8.32	31	0.0072	0.0137
9	ST 9	84	8.34	31	0.0101	0.0011
10	ST 10	62	8.33	30	0.0158	0.0137
11	ST 11	58	8.32	31	0.0158	0.0262
12	ST 12	76	8.34	30	0.0130	0.0137
13	ST 13	48	8.44	30	0.0361	0.0262
14	ST 14	60	8.43	31	0.0101	0.0137
15	ST 15	72	8.45	30	0.0101	0.0262
16	ST 16	50	8.40	30	0.0014	0.0388
17	ST 17	52	8.41	32	0.0130	0.0011
18	ST 18	62	8.38	31	0.0274	0.0137
19	ST 19	50	8.38	31	0.0245	0.0011
20	ST 20	54	8.39	31	0.0158	0.0262
21	ST 21	50	8.12	31	0.0014	0.0262
22	ST 22	62	8.28	31	0.0014	0.0012
23	ST 23	50	8.33	31	0.0187	0.0011
24	ST 24	62	8.38	31	0.0014	0.0016
25	ST 25	66	8.36	31	0.0014	0.0011
26	ST 26	66	8.38	30	0.0101	0.0017
27	ST 27	76	8.40	30	0.0101	0.0011
28	ST 28	74	8.39	30	0.0158	0.0018
29	ST 29	68	8.38	31	0.0470	0.0019
30	ST 30	74	8.38	31	0.0072	0.0014
Quality standards		20 for coral and seagrass; and 80 for mangroves*	7-8.5*	33-34*	0.05*	0.005*

*Seawater quality standards are based on Government Regulation of the Republic of Indonesia Number 22 of 2021 on the Implementation of Environmental Protection and Management.

B. Nickel

The heavy metal Ni, if it is based on sediment quality guidelines according to Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario, 1993 has passed the sediment quality standards set at 4 stations, namely ST 20, 21, 22 and ST 23 (**Figure 5**). This describes that the presence of Ni in the sediment has had a negative impact on marine biota that live and feed around/on the sediment or the bottom of the waters around the 4 stations. Indirectly, this will have a significant impact on human health through the food chain.

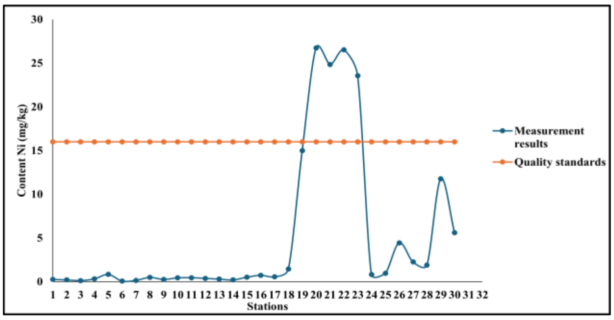

Fig 5. Comparison graph between the Ni content from the measurement results (blue) and the sediment quality standards (orange).

Stations contaminated with heavy metal Ni in sediments are located around the nickel mining area of the research area (**Figure 6**). Nickel is an element that is naturally found in water, air and soil. Nickel comes from natural sources and anthropogenic activities. Environmental pollution due to nickel can be caused by rock weathering, mining activities, industry, fuel use, pesticide use, as well as industrial waste, domestic waste and so on (Ali and Khan, 2018; Genchi et al., 2020). Based on this, it is indicated that the origin of heavy metal contamination Ni in the research area is due to weathering of ultramafic rocks containing heavy metal Ni, then experiencing erosion and transportation to the sea and entering sea waters which then settle in sediments. nickel mining activities, ship waste passing through the waters of the research area and shipping activities that use fuel around the research area.

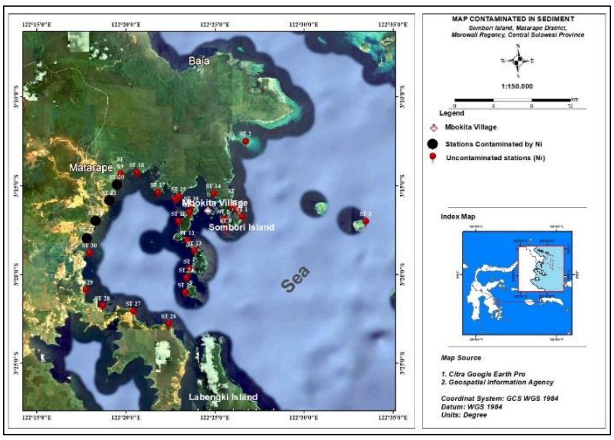

Fig 6. Distribution map of stations that experienced heavy metal contamination with Ni (black) and those that did not experience Ni contamination (red) (modified from Rusmana et al., 1993)

Nickel is one of the nutrients needed by living things including humans within certain limits. However, if it exceeds the established standards, it will have an impact on health such as respiratory cancer, dermatitis, reproductive disorders, allergies, cardiovascular disease, kidney, lung and nose cancer and breast cancer (Buxton et al., 2019; Genchi et al., 2020).

Table 2. Results of measurements of heavy metal content Cr and Nickel in marine sediments in the research area.

No	Station	Heavy metals in marine sediments (mg/kg)	
		Chromium (Cr)	Nickel (Ni)
1	ST 01	0.3431	0.2525
2	ST 02	0.3348	0.2022
3	ST 03	0.2598	0.1283
4	ST 04	0.2681	0.3234
5	ST 05	0.6263	0.8320
6	ST 06	0.2681	0.0721
7	ST 07	0.3181	0.1519
8	ST 08	0.5014	0.4920
9	ST 09	0.4347	0.2643
10	ST 10	0.6097	0.4388
11	ST 11	0.8429	0.4565
12	ST 12	0.4097	0.3855
13	ST 13	0.5180	0.2968
14	ST 14	0.4847	0.2052
15	ST 15	0.2931	0.5127
16	ST 16	0.6347	0.7315
17	ST 17	0.5847	0.5688
18	ST 18	1.0262	1.4411
19	ST 19	9.4143	14.998
20	ST 20	19.077	26.748
21	ST 21	14.850	24.856
22	ST 22	73.163	26.526
23	ST 23	32.471	23.561
24	ST 24	0.7096	0.8083
25	ST 25	1.1261	0.9651
26	ST 26	1.7259	4.4452
27	ST 27	1.0428	2.2631
28	ST 28	1.1678	1.8994
29	ST 29	3.3502	11.778
30	ST 30	3.4335	5.6072
Quality standards		**260***	**16****

* Standard values for marine sediment quality according to Department of Ecology State of Washington, 2013 chapter WAC 173-204-320.
** Sediment quality guideline values for heavy metals according to Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario, 1993.

Conclusion

The content of heavy metals in seawater in the form of Ni has a content value that is still below the established seawater quality standards, while the content of heavy metals Cr6+ has exceeded the established quality standards. The content of heavy metals Ni in marine sediments has exceeded the established sediment quality standards, while the content of heavy metals Cr is still below the established quality standards. The impact of the heavy metal content of Cr6+ in water and Ni content in marine sediments has polluted the marine environment so that it has a negative impact on marine ecosystems including humans through the food chain. Sources of contamination of heavy metals in water and sediment are from the weathering of ultramafic rocks containing heavy metals, mining activities, shipping activities using fossil fuels, the use of ship paint containing heavy metals, solid waste from ships containing heavy metals and domestic waste.

Acknowledgements

This research was made possible by financial support from Naturevolution France. The authors would like to thank the Head of the Institute for Research and Community Service of Halu Oleo University and the Dean of the Faculty of Mathematics and Natural Sciences of Halu Oleo University for their support in this research. Special thanks to the Naturevolution Indonesia team and the Sombori Island expedition team, Central Sulawesi for their assistance, cooperation, discussion and togetherness during this research.

References

Ahmad, W., 2001. Nickel Laterites-A Training Manual: Chemistry, Mineralogy & Formation of Ni Laterites. Pt. Inco.

Ali, H., Khan, E., 2018. Bioaccumulation of non-essential hazardous heavy metals and metalloids in freshwater fish. Risk to human health. Environ. Chem. Lett. 16, 903–917. https://doi.org/10.1007/s10311-018-0734-7

August 1993, 1993. Weatherwise 46, 47–52. https://doi.org/10.1080/00431672.1993.9930274

Bilotta, G.S., Brazier, R.E., 2008. Understanding the influence of suspended solids on water quality and aquatic biota. Water Res. 42, 2849–2861. https://doi.org/10.1016/j.watres.2008.03.018

Buxton, S., Garman, E., Heim, K.E., Lyons-Darden, T., Schlekat, C.E., Taylor, M.D., Oller, A.R., 2019. Concise review of nickel human health toxicology and ecotoxicology. Inorganics 7. https://doi.org/10.3390/inorganics7070089

Department of Ecology State of Washington, 2013. Sediment management standards, Sediment Management Standards.

DesMarias, T.L., Costa, M., 2019. Mechanisms of chromium-

induced toxicity. Curr. Opin. Toxicol. 14, 1–7. https://doi.org/10.1016/j.cotox.2019.05.003.
Elias, M., 2002. Nickel Laterite Deposits-Geological Overview, Resources and Exploitation. Giant Ore Deposits: Characteristics, Genesis and Exploration. CODES Special Publication, 4. 205-220.
Genchi, G., Carocci, A., Lauria, G., Sinicropi, M.S., Catalano, A., 2020. Nickel: Human health and environmental toxicology. Int. J. Environ. Res. Public Health 17. https://doi.org/10.3390/ijerph17030679
Hamilton, W.B., 1979. Tectonics of the Indonesian Region. U.S. Govt. Print. Off.,. https://doi.org/10.3133/pp1078
Hasria., Anshari, E., Muliddin., Restele, L.O., Zulkifli, L.O.M., 2019. The Influence of Geological Structure on the Distribution of Nickel (Ni) and Iron (Fe) Content in Nickel Laterite Deposits of the Saprolite Zone of PT. Manunggal Sarana Surya Pratama, Lasolo Islands District, North Konawe Regency, Southeast Sulawesi (in Indonesian). J. Ris. Teknol. Pertamb. 6, 38–45.
Hasria., Anshari, E., Rezky, T.B., 2019. The Influence of Bedrock and Geomorphology on Laterization and Distribution of Ni and Fe Content in Laterite Nickel Deposits of PT. Bumi Sulawesi Mine, Pongkalaero Village, Bombana Regency, Southeast Sulawesi (in Indonesian).. J. Geogr. Apl. Dan Teknol. 3, 47–58.
Hasria dan Sara Septiana, 2024. Geology of Nickel Laterite Deposits (in Indonesian), Deepublish.
Hasria, H., Anshari, E., Restele, L.O., Deniyatno, D., Firdaus, F., Muliddin, M., Okto, A., Suparwi, S., 2021a. The Influence of Geological Structure on Nickel Laterite Deposits in North Konawe Regency, Southeast Sulawesi (in Indonesia). JAGAT (Jurnal Geogr. Apl. dan Teknol. 5, 95. https://doi.org/10.33772/jagat.v5i1.17079
Hasria, H., Asfar, S., Ngkoimani, L.O., Okto, A., Jaya, R.I.M.C., Sepdiansar, R., 2021b. The Influence of Geomorphology on the Distribution Pattern of Nickel and Iron Elements in Laterite Nickel Deposits in Central Buton Regency, Southeast Sulawesi (in Indonesian). J. GEOSAPTA 7, 103. https://doi.org/10.20527/jg.v7i2.10716.
Hasria., Asfar, S., Tawakkal, E.R., 2021c. Profile of Laterite Nickel Deposits, at Tinanggea District, South Konawe Regency, Southeast Sulawesi Province. Jurnal Promine : 9, 1–10. https://doi.org/10.33019/promine.v9i1.2345
Hasria, Jaya, R.I., Awadh, S.M., Riskiyanti, Deniyatno, Syahrul, Septiana, S., 2024a. Mineralogy and Geochemical Characteristics of Lateritic Nickel Deposit in Wiwirano District, North Konawe, SE Sulawesi, Indonesia. Iraqi Geol. J. 57, 171–183. https://doi.org/10.46717/igj.57.2C.13ms-2024-9-21.
Hasria, Ruliansyah, L.M., Awadh, S.M., Masri, Azzaman, M.A., Okto, A., Sawaludin, 2024b. Identification of Lateritic Nickel Deposits Potential in the Kokoe Area, Kabaena Island, Central Buton Regency, Southeast Sulawesi Province, Indonesia. Iraqi Geol. J. 57, 179–193. https://doi.org/10.46717/igj.57.1A.15ms-2024-1-26.
Kadarusman, A., Miyashita, S., Maruyama, S., Parkinson, C.D., dan Ishikawa, A., 2004. Petrology, Geochemistry and Paleogeographic Reconstruction of the East Sulawesi Ophiolite, Indonesia. Tectonophysics. 55-83.
Khare, N., Bajpai, J., Bajpai, A.K., 2018. Graphene coated iron oxide (GCIO) nanoparticles as efficient adsorbent for removal of chromium ions: Preparation, characterization and batch adsorption studies. Environ. Nanotechnology, Monit. Manag. 10, 148–162. https://doi.org/10.1016/j.enmm.2018.06.002.
Laing, G.D., Vos, R.D, Vandecasteele, B., Lesage, E., Tack, F.M.G and Verlo., 2007. Effect of salinity on heavy metal mobility and availability in intertidal sediments of the Scheldt estuary. Estuarine, Coastal and Shelf Science 77 (2008) 589-602. https://doi.org/10.1016/j.ecss.2007.10.017.
Linos, A., Petralias, A., Christophi, C.A., Christoforidou, E., Kouroutou, P., Stoltidis, M., Veloudaki, A., Tzala, E., Makris, K.C., Karagas, M.R., 2011. Oral ingestion of hexavalent chromium through drinking water and cancer mortality in an industrial area of Greece - An ecological study. Environ. Heal. A Glob. Access Sci. Source 10, 1–8. https://doi.org/10.1186/1476-069X-10-50
Maulana, A., Bröcker, M., Dan, W., 2020. Petrogenesis and geochronology of Cenozoic intrusions in the Poboya and Sassak gold and copper districts in Western Sulawesi, Indonesia: Implications for the mineralization processes and magma sources. J. Asian Earth Sci. 193, 104303. https://doi.org/10.1016/j.jseaes.2020.104303
Permana, H., 2013. Ophiolite Complex in Surono and U. Hartono (Ed.), Geology of Sulawesi, LIPI Press, Jakarta.
Government Regulation of the Republic of Indonesia Number 22 of 2021 on the Implementation of Environmental Protection and Management. 1, 1–483.
Persuad, D., Jaagumagi, R., and Hayton, A., 1993. Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario. Ontario Ministry of Environment and Energy.
Rusmana. E, Sukido, Sukarna. D, Haryono. E, and S.T.O., 1993. Geological Map of Lasusua-Kendari Sheet, Sulawesi. Geological Research and Development Center, Bandung.
Syaifudin, M., Moussa, M.G., Li, T and Du, H., 2025. The impact of salinity on heavy metal accumulation in seaweed. Marine Pollution Bulletin, 214, 117819. 10.1016/j.marpolbul.2025.117819
van Leeuwen, T.M., Pieters, P.E., 2011. Mineral Deposits of Sulawesi. Proc. Sulawesi Miner. Resour. Semin. MGEI-IAGI 1–10. https://doi.org/10.13140/2.1.3843.2322