Pharmacogn J. 2024; 16(5): 1159-1163
A Multifaceted Journal in the field of Natural Products and Pharmacognosy
www.phcogj.com

Research Article

Probabilistic Simulation and Sensitivity of Health Risks from Nickel and Cobalt Deposition Around the Mine

Sherly Wulandari[1]*, Anwar Mallongi[2], Budimawan[3], Agus Bintara Birawida[4], Nur Nasry Noor[5], M. Alimin Maidin[6]

ABSTRACT

Background: Mining activities can produce large amounts of heavy metals that are discharged uncontrollably, causing widespread ecosystem pollution. Heavy metal pollution is a serious problem, as heavy metals are toxic and non-degradable, polluting air, water and soil. Although some heavy metals are considered essential for normal physiological functions, concentrations that exceed the prescribed limits can have negative impacts on human health and biota. Exposure to heavy metals can cause toxicity to various tissues, organs and systems such as circulatory, respiratory, endocrine, immune, nervous, urinary and reproductive systems. Due to the differences in toxicity of heavy metals, risk assessment is very important in environmental management. **Objective**: To describe the probabilistic simulation and sensitivity of health risks due to Nickel and Cobalt deposition around the mine using monte carlo simulation. **Methods:** The method used in this study was *literature review*. Data collection was done through searching *online databases* such as: *Pubmed* and *Science Direct*. The keywords used in the article search were "*Heavy Metal Toxicity*", "*Heavy Metal Effects*", "*Heavy metal risk analysis" and "Monte Carlo Simulation"*. Inclusion criteria were quantitative or qualitative research, target population was heavy metals *Nickel* and *Cobalt*, published in the last 10 years (2013-2023) articles in English and articles in original, *fulltext and open access*. Exclusion criteria are articles that are not relevant to the topic of discussion. **Results:** 14 articles were found, of which 3 articles on diseases or health problems caused by nickel, 3 articles on nickel risk analysis, 5 articles on diseases or health problems caused by cobalt, 3 articles on cobalt risk analysis. **Conclusion:** The environment around the mine shows a high level of toxicity, caused by the presence of heavy metals. This can result in serious environmental pollution and pose a great threat to human health. Chronic exposure to heavy metals can cause various health problems, such as mutagenesis, carcinogenesis, teratogenesis, deformation and organ damage.
Keywords: Heavy metal contamination, Nikel, Cobalt, health risk, Monte Carlo Simulation.

Sherly Wulandari[1]*, Anwar Mallongi[2], Budimawan[3], Agus Bintara Birawida[4], Nur Nasry Noor[5], M. Alimin Maidin[6]

[1]Doctoral Program Student, Faculty of Public Health, Hasanuddin University, Makassar, INDONESIA.

[2]Environmental Health Department, Faculty of Public Health, Hasanuddin University, Makassar, INDONESIA.

[3]Department of Marine Science, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, INDONESIA.

[4]Environmental Health Department, Faculty of Public Health, Hasanuddin University, Makassar, INDONESIA.

[5]Department of Epidemiology, Faculty of Public Health, Hasanuddin University, Makassar, INDONESIA.

[6]Department of Health Administration and Policy, Faculty of Public Health, Hasanuddin University, Makassar, INDONESIA.

Correspondence

Sherly Wulandari

Doctoral Program Student, Faculty of Public Health, Hasanuddin University, Makassar, INDONESIA.

E-mail: sherlywulandari101@gmail.com

History

- Submission Date: 02-07-2024;
- Review completed: 15-09-2024;
- Accepted Date: 21-09-2024.

DOI : 10.5530/pj.2024.16.189

Article Available online

http://www.phcogj.com/v16/i5

INTRODUCTION

Contamination of potentially toxic metals in air, soil, water, and food products remains a global concern[1]. These potentially toxic heavy metals can originate from geogenic and anthropogenic activities [2]. However, most environmental pollution and human exposure comes from anthropogenic activities such as mining, household and agricultural activities, and the use of metal-containing compounds [3]. These heavy metals are persistent in the environment, contaminate the food chain, and cause various health problems due to their toxicity [4].

The alarming level of toxicity makes heavy metals such as As, Cd, Hg, and Pb, Ni and Co rank highest among the 10 heavy metals that are the focus of most concern in maintaining public health [5]. Heavy metals are prioritized for human health considering exposure to metal mine dust, including the transition metals Co, Cu, Ni and Zn due to their ability to generate reactive oxygen species (ROS) in biological tissues via Fenton's reaction [5].

After entering the environment, heavy metals have the potential to accumulate in the food chain, causing serious ecological impacts. In addition, these metals can have carcinogenic effects and adverse impacts on human health. Accumulation of heavy metals over a long period of time, especially through the consumption of foodstuffs such as fish, can result in chronic accumulation involving mutagenesis, carcinogenesis, teratogenesis, deformation, and organ damage [6].

Mining activities can generate large quantities of heavy metal-containing wastes that are released uncontrollably, causing widespread ecosystem pollution [7]. All of the environmental components such as soil, sediment, air, water, flora and fauna can be severely impacted [8]. Dust generated from the mining process has physico-chemical compound properties [9]. These particles can be carried by the wind and pollute the air around the mine [10] adverse impact on air quality and human health, especially for people living in the vicinity [11].

Exposure to heavy metals in humans can be through inhalation, oral and skin contact which has a negative impact on human health [11]. Exposure through inhalation can cause damage to the respiratory system, such as irritation of the respiratory tract, coughing, and shortness of breath. Oral exposure includes organ damage, metabolic disorders, and the potential for acute toxicity such as gastrointestinal irritation, nausea, and vomiting and dermal exposure causes skin irritation, dermatitis, and even skin cancer [12].

Some previous studies that discuss heavy metal contamination of nickel and cobalt children have a

Cite this article: Wulandari S, Mallongi A, Birawida AB, Budimawan, Noor NN, Maidin MA. Probabilistic Simulation and Sensitivity of Health Risks from Nickel and Cobalt Deposition Around the Mine. Pharmacogn J. 2024;16(5): 1159-1163.

high risk of contamination due to frequent activities such as putting their hands in their mouths and the occurrence of asthma in children living near mining sites [13]. In addition to children, heavy metal contamination also has a negative impact on the lungs of workers and communities living around the mine due to decreased air quality, ultimately causing Acute Respiratory Infections (ARI) [14].

Therefore, efforts to prevent heavy metal pollution need to be carried out through health risk assessment using the monte carlo simulation model recommended by United Static Environmental Protection Agency 2009. Given that the purpose of probability in the context of risk assessment is to measure the level of uncertainty in pollutant concentrations, it is important to recognize the importance of probability [15].

Based on the negative impacts of nickel and cobalt heavy metals and previous research on pollutants in air, water and soil contaminated with nickel and cobalt heavy metals. For this reason, literature study-based research is needed related to "Probabilistic Simulation and Sensitivity of Health Risks Due to Nickel and Cobalt Deposition Around Mining". So that it can be a recommendation for further improvement and evaluation for companies and governments, related to efforts to reduce exposure sources and impacts that may arise.

METHODS

The method used in writing this article is a literature review, namely research by reviewing several articles both nationally and internationally. The source of literature in this study is mainly from online database journals that provide journal articles in PDF format such as: Pubmed, Science Direct Elsevier. Other reference sources that were also utilized were theses and dissertations. To keep the information up-to-date, the literature used mainly comes from literature collected over the last 10 (ten) years (spanning 2013 to 2023).

There were 14 articles that met the inclusion criteria, namely: 1) quantitative or qualitative research and other studies relevant to the purpose of the literature review; 2) the target population is heavy metals nickel and Cobalt; 3) published between 2013-2023; 4) articles in English; and 5) articles in *fulltext*. The following word combinations were used in the search: "*Pathways of exposure AND nickel", "Impact of exposure to nickel AND humans AND air", "Impact of exposure to nickel AND air AND the environment", "Impact of nickel AND human exposure", "Risk analysis due to nickel exposure on humans", "Pathways of exposure AND cobalt", "Impact of exposure to cobalt AND humans AND air", "Impact of exposure to cobalt AND air AND the environment", "Impact of cobalt AND human exposure", "Risk analysis due to cobalt exposure on humans" and "Monte Carlo Simulation"*. The following prism diagram of the literature search is presented in Figure 1.

RESULTS AND DISCUSSION

Based on the results of the literature review on 14 articles, the authors found that in water, soil and air pollution due to heavy metals nickel and cobalt are the most common components. The articles analyzed have main themes, such as "diseases / health problems due to heavy metals nickel and cobalt" and "health risk analysis on heavy metals nickel and cobalt". Presented in the following table:

Industrial developments such as metal plating and mining lead to increased concentrations of heavy metals in water, soil and air, potentially triggering health problems [19]. Carcinogens such as nickel, cadmium, chromium, arsenic and beryllium can cause brain cancer [20]. Workers exposed to industrial dust with high heavy metal content may experience allergic reactions and respiratory problems [21]. Exposure to nickel, especially from mining environments, can cause a range of health problems including allergies, DNA damage, neurological disorders, and risk of cardiovascular, lung, and kidney diseases. Nickel

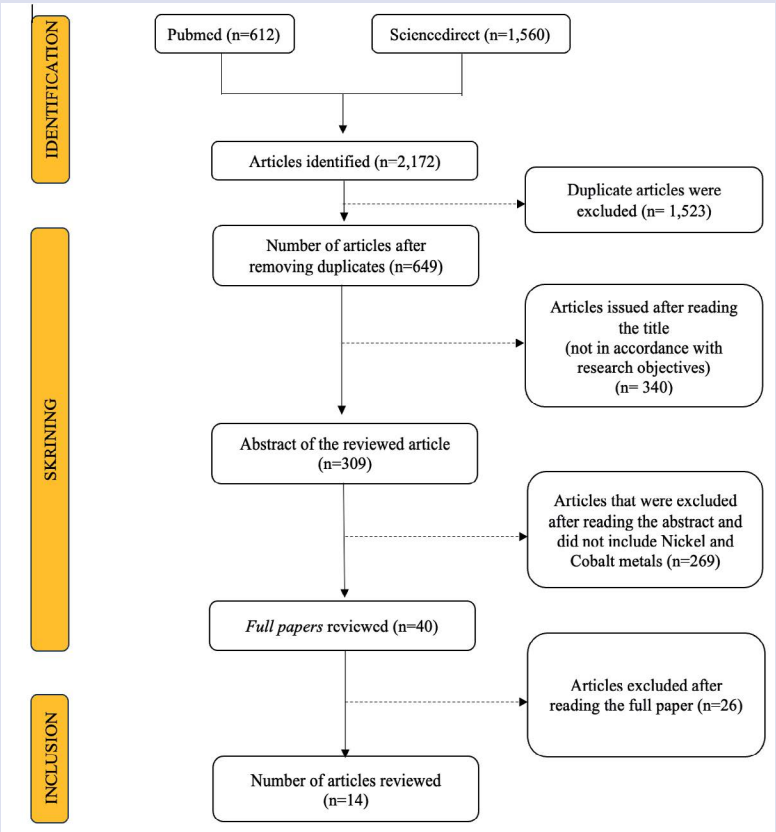

Figure 1. Prism Study Flow Chart.

Table 1. Diseases/Health Problems Due to Nickel (Ni).

No.	Title	Study Design	Results	Existence	SoSource
1	*Effects of Nickel at Environmentally Relevant Concentrations on Human Corneal Epithelial Cells: Oxidative Damage and Cellular Apoptosis*	Human Corneal Epithelial Cells *(HCEC)*	Ni exposure may contribute to the risk of dry eye, mainly through the mechanisms of oxidative damage and induction of apoptosis in human corneal epithelial cells.	Air and water	[16]
2	*Environmental Nickel Exposure and Diabetes in a Nationally Representative Sample of US Adults*	Probability Sampling	Individuals with diabetes had higher urinary nickel concentrations compared to those without diabetes. This suggests a correlation between nickel exposure and diabetic conditions.	Food, water and air	[17]
3	*Dose-Response Relationship between Environmental Exposure to Nickel and Pulmonary Function in the Korean General Population Aged 40 or Older*	Korean National Health and Nutrition Examination Survey *(KNHANES)*	It showed that the level of nickel in the blood can affect lung health in Korean men aged 40 years or older.	Air	[18]

Table 2. Nickel (Ni) Risk Analysis.

No.	Title	Analysis Method	Results	Existence	Source
1	*Evaluation of nickel toxicity and potential health implications of agriculturally diversely irrigated wheat crop varieties*	Randomized Whole Block Design (RCBD)	nickel concentrations in soil and grains were within safe limits and all Ni indices were less than 1.	Groundwater (GW), sewage water (SW) and industrial wastewater (IW)	[24]
2	*Comparative Study of Potentially Toxic Nickel and Their Potential Human Health Risks in Seafood (Fish and Mollusks) from Peninsular Malaysia*	Flame Atomic Absorption Spectrophotometer (FAAS)	Consumption of nickel-contaminated seafood does not pose a non-carcinogenic risk and therefore has no adverse impact on society.	Food	[25]
3	*Calcium-dependent cyto- and genotoxicity of nickel metal and nickel oxide nanoparticles in human lung cells*	Photon Cross-Correlation Spectroscopy (PCCS), inductively coupled plasma mass spectrometry (ICP-MS) and The annexin V-FITC/propidium iodide (PI) kit (Calbiochem).	Demonstrated that Ni and NiO as well as Ni ionic species trigger chromosome damage in human lung cell lines	Air	[26]

Table 3. Diseases/Health Problems Due to Cobalt (Co).

No.	Title	Study Design	Results	Existence	Source
1	*Work-related asthma in cobalt-exposed workers*	Interview	Cobalt-exposed workers develop two lung conditions: asthma or pulmonary fibrosis.	Air	[30]
2	*Effects of occupational cobalt exposure on the heart in the production of cobalt and cobalt compounds: a 6-year follow-up*	Observation Study	Cobalt exposure affects the heart muscle very little compared to the impact of physiological changes due to aging, medication and traditional cardiovascular factors such as increased blood pressure.	Air	[31]
3	*Urinary cobalt and ferritin in four-year-old children*	Questionnaire	children with iron deficiency anemia statistically showed a much higher urine Co concentration than children without iron deficiency anemia.	air, water and food	[32]
4	*Hard Metal Lung Disease: Updates in Diagnosis and Management*	Literature Review	Exposure to hard metal lung diseases such as Cobalt causes asthma and parenchymal lung diseases that can potentially lead to respiratory failure	Air	[33]
5	*Dermal and inhalable cobalt exposure-Uptake of cobalt for workers at Swedish hard metal plants*	Observation study and laboratory analysis	There is a significant correlation between exposure to cobalt in air and cobalt uptake in blood and urine. The absorption of cobalt in the blood and urine is absorbed through the skin and or through direct consumption of cobalt-contaminated food.	Air	[34]

can also displace zinc in the body, resulting in changes to normal protein function. The incidence of obesity can also be affected by exposure to certain pollutants such as phthalate and perfluoroalkyl metabolites [22,23].

Exposure to heavy metals in various regions, mainly associated with industries such as oil production and mining, leads to significant levels of pollution. Health risk evaluations indicate potentially adverse carcinogenic and non-carcinogenic risks, especially in children. The content of heavy metals such as Cr, Ni and Pb exceeded the threshold values of soil elements at some sites, posing potential ecological hazards [27]. Health risk assessments in metal-producing regions such as Southeast Asia and Melanesia highlight the difficulty of applying risk models without adjustments for different geochemical conditions and animal physiology [28]. Studies on heavy metal exposure in aquatic environments show variable correlations between water, sediment and fish tissue, with health implications for aquatic organisms [29]. In urban environments, heavy metal pollution levels can vary, and dust from vehicle and industrial fumes can pose health risks in certain areas.

Table 4. Cobalt (Co) Risk Analysis.

No.	Title	Analysis Method	Results	Existence	Source
1	*Assessing the environmental risk and mobility of cobalt in sediments near nonferrous metal mines with risk assessment indexes and the diffusive gradients in thin films (DGT) technique*	The Potential Human Health Risk	Sand mining activities make a major contribution to Co releases showing that Co tends to migrate across the sediment-water interface at all sampling locations. Thus posing an environmental risk	Water	[37]
2	*Cobalt toxicity in humans-A review of the potential sources and systemic health effects*	The Potential Human Health risk	It indicates that Co has an impact on systemic health characterized by complex clinical syndromes mainly including neorological (hearing and vision impairment), cardiovascular and endocrine deficits.	Food	[38]
3	*Cobalt's Role in Modulating Antioxidant Systems and Semen Quality in Males*	The Potential Human Health Risk and Ecological Risk	Cobalt metal exposed through the air negatively affects male fertility by promoting an imbalance between reactive oxygen (ROS) production and the body's anti-oxidant defenses, which causes sperm DNA damage, decreased sperm motility and decreased sperm count.	Air	[39]

The use of Cobalt is considered crucial in achieving energy transformation, decarbonization, and green transport to support sustainable development and net zero emission transition [35]. Although it has important functions in human metabolism in small amounts, large-scale exposure to Cobalt can be toxic to the body. Airborne Cobalt exposure can negatively affect male fertility by causing an imbalance between reactive oxygen production and the body's antioxidant defenses, resulting in sperm DNA damage, decreased motility and low sperm count. In addition, exposure to Cobalt through various sources such as air, water, food, drink, and skin can cause a variety of chronic diseases, including lung cancer, kidney failure, reproductive disorders, and damage to human DNA [36]. With the largest battery industry in Indonesia, Cobalt exposure in mining areas may increase, increasing the risk of negative impacts on public health.

Risk assessments of mining activities show that small-scale artisanal mining, especially in children and artisanal miners without personal protection, can result in significant health impacts. The results show that mining areas are polluted, with the highest non-cancer risks in children, mainly related to concentrations of heavy metals such as cobalt. At a gold mining site in Obuasi, Ghana, a Potential Ecological Risk (PER) analysis showed that most of the surrounding communities face high risks to ecological systems from metal contamination. Cobalt and mercury (Hg) contributed significantly to such risks [40]. In addition, mining-induced air pollution, especially particulate matter (PM), is a major concern. Studies in China assessed the health risks associated with inhalation of PM2.5 and PM10 related to six heavy metals (arsenic, chromium, cadmium, nickel, cobalt and lead). Cobalt (Co) and chromium (Cr) showed significant contributions to non-carcinogenic and cancer risks, with Co accounting for most of the non-carcinogenic risks after inhalation exposure [41]

CONCLUSIONS

The mining industry increases concentrations of heavy metals in groundwater and air, potentially causing health problems. Exposure to nickel and cobalt in mining has health impacts including allergies, DNA damage, neurological disorders, and risk of cardiovascular, lung, and kidney diseases Heavy metal pollution from the mining industry creates significant levels of pollution, with carcinogenic and non-carcinogenic risks especially in children. Therefore, mitigation and environmental management measures are crucial to protect human and ecosystem health, especially in mining areas.

ACKNOWLEDGMENT

The highest gratitude and appreciation to previous researchers who have provided a lot of new knowledge and insights, as well as to Prof. Anwar Mallongi, SKM, MSc, Ph.D as the supervisor for guidance and advice so that the author can complete the writing of the *literature review* article properly and correctly to completion.

REFERENCES

1. Mallongi, A., Astuti, R. D. P., Amiruddin, R., Hatta, M. & Rauf, A. U. Identification source and human health risk assessment of potentially toxic metal in soil samples around karst watershed of Pangkajene, Indonesia. *Environ Nanotechnol Monit Manag* 17, 100634 (2022).
2. Ali, H., Khan, E. & Ilahi, I. Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation. *J Chem* 2019, 1–14 (2019).
3. Astuti, R. D. P. Dynamic Model of Heavy Metals Pollution Based on Environmental Health Risk Analysis in Pangkajene Coastal Area. (2022).
4. Ali, H., Khan, E. & Ilahi, I. Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. *Journal of Chemistry* vol. 2019 Preprint at https://doi.org/10.1155/2019/6730305 (2019).
5. Agency for toxic substances and disease registry. Toxic substances . *Atlanta:ATSDR* (2018).
6. Adegbola, I. P., Aborisade, B. A. & Adetutu, A. Health risk assessment and heavy metal accumulation in fish species (Clarias gariepinus and Sarotherodon melanotheron) from industrially polluted Ogun and Eleyele Rivers, Nigeria. *Toxicol Rep* 8, 1445–1460 (2021).
7. Muibat Omotola Fashola, V. M. N.-J. and O. O. B. Heavy Metal Pollution from Gold Mines: Environmental Effects and Bacterial Strategies for Resistance. (2016).
8. Eisa SOLGI, J. P. Analysis and assessment of nickel and chromium pollution in soils around Baghejar Chromite Mine of Sabzevar Ophiolite Belt, Northeastern Iran. (2015).
9. Ting Liu, S. L. The impacts of coal dust on miners' health: A review. *Environ Res* 190, 1–18 (2020).
10. Reno Fitriyanti. PERTAMBANGAN BATUBARA DAMPAK LINGKUNGAN, SOSIAL DAN EKONOMI. *Pertambangan Batubara : Dampak Lingkungan, Sosial dan Ekonomi* 1, (2016).
11. Nurfatimah. POTENSI PENCEMARAN LINGKUNGAN AKIBAT AKTIVITAS PERTAMBANGAN PADA KAWASAN INDUSTRI KAB. BANTAENG. 58–64 (2023).
12. Miaratiska, N. , A. R. Hubungan paparan nikel dengan gangguan kesehatan kulit pada pekerja industri rumah tangga pelapisan logam di Kabupaten Sidoarjo. *Perspektif jurnal Kesehatan Lingkungan* 1, 25–36 (2015).

13. Jane A. Entwistle, A. S. H. A. G. S. Metalliferous Mine Dust: Human Health Impacts and the Potential Determinants of Disease in Mining Communities. 5, 67–83 (2019).
14. Musrifa Kudus, E. A. J. A. S. L. S. Analysis of Increasing Case of Acute Respiratory Infections (ARI) in Nickel Mining Environment in Pomalaa District, Kolaka Regency, Southeast Sulawesi. 1, 52–57 (2022).
15. Dehghani, F., Omidi, F., Fallahzadeh, R. A. & Pourhassan, B. Health risk assessment of occupational exposure to heavy metals in a steel casting unit of a steelmaking plant using Monte–Carlo simulation technique. *Toxicol Ind Health* 37, 431–440 (2021).
16. Zhang, Z.-N. *et al.* Effects of Nickel at Environmentally Relevant Concentrations on Human Corneal Epithelial Cells: Oxidative Damage and Cellular Apoptosis. *Biomolecules* 12, 1283 (2022).
17. Titcomb, T. J., Liu, B., Lehmler, H., Snetselaar, L. G. & Bao, W. Environmental Nickel Exposure and Diabetes in a Nationally Representative Sample of US Adults. *Expo Health* 13, 697–704 (2021).
18. Joh, J.-S., Kang, M.-Y. & Myong, J.-P. Dose–Response Relationship between Environmental Exposure to Nickel and Pulmonary Function in the Korean General Population Aged 40 or Older. *Int J Environ Res Public Health* 18, 7016 (2021).
19. M. Wieczorek-Dąbrowska, A. T.-M. B. P. dan A. B.-R. Roe and red deer as bioindicators of heavy metals contamination in north-western Poland. 29, no. 2, 100–110 (2013).
20. Nguyen, H. D. Prognostic biomarker prediction for glioma induced by heavy metals and their mixtures: An in-silico study. *Toxicol Appl Pharmacol* 459, 116356 (2023).
21. Ahmed, Md. S. *et al.* Risk assessment and evaluation of heavy metals concentrations in blood samples of plastic industry workers in Dhaka, Bangladesh. *Toxicol Rep* 7, 1373–1380 (2020).
22. Liao, S. *et al.* Association of aldehydes exposure with obesity in adults. *Ecotoxicol Environ Saf* 201, 110785 (2020).
23. Alderete, T. L. *et al.* Perfluoroalkyl substances, metabolomic profiling, and alterations in glucose homeostasis among overweight and obese Hispanic children: A proof-of-concept analysis. *Environ Int* 126, 445–453 (2019).
24. Iqbal Khan, Z. *et al.* Evaluation of nickel toxicity and potential health implications of agriculturally diversely irrigated wheat crop varieties. *Arabian Journal of Chemistry* 16, 104934 (2023).
25. Yap, C. K. & Al-Mutairi, K. A. Comparative Study of Potentially Toxic Nickel and Their Potential Human Health Risks in Seafood (Fish and Mollusks) from Peninsular Malaysia. *Biology (Basel)* 11, 376 (2022).
26. Di Bucchianico, S. *et al.* Calcium-dependent cyto- and genotoxicity of nickel metal and nickel oxide nanoparticles in human lung cells. *Part Fibre Toxicol* 15, 32 (2018).
27. Gan, L., Wang, J., Xie, M. & Yang, B. Ecological risk and health risk analysis of soil potentially toxic elements from oil production plants in central China. *Sci Rep* 12, 17077 (2022).
28. Peters, A. *et al.* Validation of the nickel biotic ligand model for locally relevant species in Australian freshwaters. *Environ Toxicol Chem* 37, 2566–2574 (2018).
29. Díaz-de-Alba, M., Granado-Castro, M. D., Galindo-Riaño, M. D. & Casanueva-Marenco, M. J. Comprehensive Assessment and Potential Ecological Risk of Trace Element Pollution (As, Ni, Co and Cr) in Aquatic Environmental Samples from an Industrialized Area. *Int J Environ Res Public Health* 18, 7348 (2021).
30. Al-abcha, A., Wang, L., Reilly, M. J. & Rosenman, K. D. Work-related asthma in cobalt-exposed workers. *Journal of Asthma* 58, 1032–1041 (2021).
31. Linna, A. *et al.* Effects of occupational cobalt exposure on the heart in the production of cobalt and cobalt compounds: a 6-year follow-up. *Int Arch Occup Environ Health* 93, 365–374 (2020).
32. Junqué, E., Grimalt, J. O., Fernández-Somoano, A. & Tardón, A. Urinary cobalt and ferritin in four-years-old children. *Environ Res* 183, 109147 (2020).
33. Zheng, M., Marron, R. M. & Sehgal, S. Hard Metal Lung Disease: Update in Diagnosis and Management. *Curr Pulmonol Rep* 9, 37–46 (2020).
34. Wahlqvist, F., Bryngelsson, I.-L., Westberg, H., Vihlborg, P. & Andersson, L. Dermal and inhalable cobalt exposure—Uptake of cobalt for workers at Swedish hard metal plants. *PLoS One* 15, e0237100 (2020).
35. Landau, D. & Binder, K. *A Guide to Monte Carlo Simulations in Statistical Physics*. (Cambridge University Press, 2021). doi:10.1017/9781108780346.
36. Tiszler, M. *et al.* Cobalt's role in modulating antioxidant systems and semen quality in males. *Reproductive Toxicology* 123, 108524 (2024).
37. Xu, F. *et al.* Assessing the environmental risk and mobility of cobalt in sediment near nonferrous metal mines with risk assessment indexes and the diffusive gradients in thin films (DGT) technique. *Environ Res* 212, 113456 (2022).
38. Leyssens, L., Vinck, B., Van Der Straeten, C., Wuyts, F. & Maes, L. Cobalt toxicity in humans—A review of the potential sources and systemic health effects. *Toxicology* 387, 43–56 (2017).
39. Tiszler, M. *et al.* Cobalt's role in modulating antioxidant systems and semen quality in males. *Reproductive Toxicology* 123, 108524 (2024).
40. Akoto, O. *et al.* Characterization, Spatial Variation and Risk Assessment of Heavy Metals and a Metalloid in Surface Soils in Obuasi, Ghana. *J Health Pollut* 8, (2018).
41. Liu, Y. *et al.* Distribution, bioaccessibility, and health risk assessment of heavy metals in PM2.5 and PM10 during winter heating periods in five types of cities in Northeast China. *Ecotoxicol Environ Saf* 214, 112071 (2021).

Cite this article: Wulandari S, Mallongi A, Birawida AB, Budimawan, Noor NN, Maidin MA. Probabilistic Simulation and Sensitivity of Health Risks from Nickel and Cobalt Deposition Around the Mine. Pharmacogn J. 2024;16(5): 1159-1163.