Assessment of Environmental Health Risks Associated with Chemical Content of Drinking Water for Workers in the Copper and Gold Mineral Ore Processing Industry

Abstract. Drinking water is a necessity for all living organisms and should be of good quality and free from hazardous contaminants. Chemical agents such as nitrate, nitrite, selenium, chromium, cadmium, manganese, cyanide, and fluoride can contaminate drinking water. Therefore, this study aims to analyze the health risks associated with these chemical agents and their potentially harmful effects on workers. The Environmental Health Risk Analysis (EHRA) method was used to evaluate the chemical agents present in the Concentrating Division area of PT Freeport Indonesia (PTFI). It was discovered that the average concentration values of all chemical agents were below the Environmental Health Quality Standards (EHQS) established in the Minister of Health Regulation Number 2 of 2023. The risk quotient (RQ) results, obtained through the division of intake and reference dose (RfD), were less than 1.

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1 INTRODUCTION

Water is a crucial compound for the survival of all living organisms, including humans (1). Approximately 50–60% of the body is made up of fluids (2,3). The body’s need for water is fulfilled through food and the daily consumption of drinking water, usually obtained from treated raw water (4,5). Raw water is not only required during household activities but also for the agricultural, tourism, industrial, and mining sectors (6,7).

In the mining sector, such as the Concentrating Division of PTFI, raw water is used for industrial activities and meeting the drinking needs of workers. Minister of Health Regulation Number 2 of 2023 stipulates 19 mandatory and 13 specific parameters that should be measured to maintain drinking water quality standards (8).

Moreover, health improvement efforts should be carried out through safety and control measures aimed at improving the drinking water quality to provide significant health benefits to the community, particularly workers.

The presence of a different color, odor, and other features in drinking water may indicate contamination, which often occurs when substances enter the water, causing quality deterioration and endangering community health (9). Therefore, water contamination control is a crucial aspect of environmental health, where EHRA is used as a valuable tool to assess potential health risks based on contamination parameters (10).

EHRA is capable of estimating carcinogenic and non-carcinogenic risk levels and can be applied in various sectors, including the mining industry. The intake of good quality drinking water is particularly important in the copper and gold mineral ore processing industry at the Concentrating Division area of PTFI. Therefore, EHRA is needed to examine concentration values and predict contamination, specifically on chemical parameters. This analysis can also be used to determine the impacts of drinking water on the health of workers (11).

2 METHOD

This study was conducted in the Concentrating Division area of PTFI from October 2022 to March 2023. Furthermore, the secondary data used were obtained from laboratory test results on the chemical parameters of water collected between 2018 and March 2023.

The data consisted of concentration values, intake values, and health risk levels for each parameter, which were calculated according to EHRA regulations (Figure 1).
The chemical parameters investigated included nitrate, nitrite, manganese, selenium, cadmium, chromium, fluoride, and cyanide, which were categorized as non-carcinogenic. The non-carcinogenic category employed chronic daily intake (CDI) as the intake formula and a Reference Dose (RfD) to determine the dose response for each parameter. In contrast, the carcinogenic category used Lifetime Average Daily Dose (LADD) and Cancer Slope Factor (CSF) to estimate risk levels.

To identify hazards related to the provision of drinking water in the workplace, this study applied the Hazard Identification Risk Assessment (HIRA) method (Figure 1). Specifically, HIRA involved the identification of potential hazards and risk factors that may cause harm, as well as risk analysis and evaluation of these hazards. After risk analysis and evaluation, risk control was carried out to determine the appropriate method for eliminating hazards or controlling risks to a minimum supposing they cannot be eliminated.
FIGURE 2.

The process of HIRA on drinking water commenced with knowing about the water supply system and the identification of hazards that could arise in the system. The risk level of each previously identified hazard was estimated, then the required prevention measure.

3 RESULTS and Discuss

3.1 Hazard Identification

This is the first stage used to identify the hazard types and impacts that may affect health. Based on laboratory tests, eight chemical parameters including nitrate, nitrite, manganese, selenium, cadmium, chromium, fluoride, and cyanide, were analyzed for their health risks when consumed over a certain period. The eight chemical parameters were found to have several health hazards. Nitrate, nitrite, and chromium can form compounds that are carcinogenic, teratogenic, mutagenic and other harmful substances (14,15). Additionally, cadmium and manganese are hazardous to health because they can cause short-term respiratory system disturbances, such as weakness, coughing, shortness of breath, bronchopneumonia, pulmonary edema, cyanosis, and methemoglobinemia. Drinking water with high levels of fluoride will cause damage to teeth and bones once consumed continuously (16).

Table 1 shows that the concentrations of the eight chemical parameters found inside the drinking water obtained from the Division area of PTFI are still below the applicable quality standards mentioned in the Indonesian Minister of Health Regulation Number 2 of 2023. The maximum allowable limits for nitrate, nitrite, cyanide, cadmium, chromium, fluoride, manganese, and selenium are 20 mg/l, 3 mg/l, 0.07 mg/l, 0.003 mg/l, 0.05 mg/l, 1.5 mg/l, 0.01 mg/l, and 0.01 mg/l, respectively.

3.2 Dose-Responses Analysis
After hazard identification, the next step in EHRA is the conduction of a dose-response analysis by determining the reference dose (RfD), reference concentration (RfC), and slope factor (SF) values of the chemical agents and their potential effects on the human body. The purpose of this analysis is to determine the exposure pathways and understand the symptoms or health effects caused by an increase in the concentration or dose of the chemical agents.

**TABLE 2** Dose-Response of Risky Chemical Agents

<table>
<thead>
<tr>
<th>Chemical Agents</th>
<th>Dose-Response</th>
<th>Critical Effects and References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate</td>
<td>1.6E+0 mg/kg/day</td>
<td>Nitrate can cause Blue Baby Syndrome or Methemoglobinemia (17).</td>
</tr>
<tr>
<td>Nitrite</td>
<td>1E-1 mg/kg/day</td>
<td>Nitrite that enters the human body in high concentrations can cause hematological and neurological effects (17).</td>
</tr>
<tr>
<td>Manganese</td>
<td>1.4E-1 mg/kg/day</td>
<td>Chronic exposure to manganese at a high dose can endanger health by targeting the nervous system (18).</td>
</tr>
<tr>
<td>Selenium</td>
<td>5E-3 mg/kg/day</td>
<td>Excess levels of selenium when consumed by humans cause nausea, vomiting, nail and hair loss, skin rashes, and nerve damage (19,20).</td>
</tr>
<tr>
<td>Cadmium</td>
<td>5E-4 mg/kg/day</td>
<td>Cadmium poisoning has occurred in Japan, causing lumbago disease which progresses to bone damage leading to softening and fracture (21).</td>
</tr>
<tr>
<td>Chromium</td>
<td>3E-3 mg/kg/day</td>
<td>Chromium causes cancer because of its carcinogenic nature when dissolved in water (15).</td>
</tr>
<tr>
<td>Fluoride</td>
<td>6E-2 mg/kg/day</td>
<td>Up to 96 households in Asembagus Sub-district are exposed to high levels of fluoride in their drinking water, which can lead to dental fluorosis (22).</td>
</tr>
<tr>
<td>Cyanide</td>
<td>2E-2 mg/kg/day</td>
<td>The effects of exposure to cyanide are neurological disorders (weakness in the muscles of the fingers and toes, difficulty walking, blurred vision, and deafness) and heart problems capable of causing coma and death (23,24).</td>
</tr>
</tbody>
</table>

The eight chemical agents entered the body through non-carcinogenic ingestion, leading to the use of the RfD value during calculation. Each chemical agent has its unique dose response. Based on Table 2, the dose response for nitrate is 1.6E+0 mg/kg/day, meaning that a dose of 1.6mg/l can pose harm to workers who consume the drinking water. Therefore, the safe and non-hazardous dose response limit is based on the RfD value for ingestion and non-carcinogenic exposure.
3.3 Exposure Analysis

The subsequent step in the EHRA involves conducting exposure analysis, which entails calculating the intake rate of the chemical agents under investigation. This calculation yields minimum, maximum, and average intake values, which are then used to determine the health risk levels associated with the contamination of these chemical agents.

The formula employed for calculating the intake rate of non-carcinogenic chemical agents is as follows:

\[ RQ = \frac{CDI}{RfD} \]

Table 3 shows the intake calculation results for the eight chemical agents found in the drinking water in the Concentrating Division area, with a weight range of 55-70 kg. An intake rate (L/day) of 1 liter/day, exposure time of 10 hours/day, exposure frequency of 250 days/year, and exposure duration of 25 years were obtained from default exposure factors.

3.4 Risk Characterization

Risk characterization is calculated using the division formula between intake (I) and the reference dose or concentration (RfD/RfC) of the chemical agents. The I variable is obtained from the exposure analysis results calculated with equation (1), while the RfD is from the dose-response analysis results cited in literature references.
3.5 Hazard Identification & Risk Assessment

The calculation results for the risk characterization of nitrate, nitrite, manganese, selenium, cadmium, chromium, fluorine, and cyanide showed an RQ < 1. This means chemical agents in drinking water found in the Concentrating Division area of PTFI are safe or non-risky. Risk management measures are implemented when RQ > 1, simply indicating that the chemical agents are not safe.

The drinking water in the Concentrating Division area of PTFI was sourced from runoff as raw water, which was then channeled to a Water Treatment Plant (WTP) and subjected to several processing stages such as filtering and disinfection. Identify hazards, hazardous events, and sources of nitrate, nitrite, manganese, selenium, cadmium, chromium, fluorine, and cyanide can come from soil and natural organic matter. Plan preventive measures for hazard by monitoring. Monitoring was carried out routinely on drinking water, such as sampling and chemical parameter tests, to ensure that the levels of chemical agents did not exceed quality standards and remained in compliance with regulations.

Preventive measures implementation and monitoring by the procedure for measuring chemical parameters in drinking water through sampling was carried out in accordance with applicable regulations. A measurement plan that could significantly prevent or reduce the hazards was implemented, followed by continuous monitoring. Proper documentation and recording of each measurement result were conducted. The results obtained were reported, and supposing any chemical parameters exceeded the quality standards, further analysis was mandatory to find a viable solution.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nitrates (mg/L)</th>
<th>Nitrites (mg/L)</th>
<th>Manganese (mg/L)</th>
<th>Selenium (mg/L)</th>
<th>Cadmium (mg/L)</th>
<th>Chromium (mg/L)</th>
<th>Fluorine (mg/L)</th>
<th>Cyanide (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>5.5 × 10^{-3}</td>
<td>4.89 × 10^{-3}</td>
<td>1.39 × 10^{-4}</td>
<td>9.78 × 10^{-3}</td>
<td>1.95 × 10^{-1}</td>
<td>1.95 × 10^{-1}</td>
<td>3.25 × 10^{-2}</td>
<td>1.95 × 10^{-2}</td>
</tr>
<tr>
<td>Max</td>
<td>2.13 × 10^{-2}</td>
<td>9.78 × 10^{-3}</td>
<td>2.05 × 10^{-2}</td>
<td>9.78 × 10^{-2}</td>
<td>1.95 × 10^{-1}</td>
<td>1.95 × 10^{-1}</td>
<td>2.11 × 10^{-1}</td>
<td>1.95 × 10^{-2}</td>
</tr>
<tr>
<td>Mean</td>
<td>2.23 × 10^{-2}</td>
<td>9.78 × 10^{-3}</td>
<td>6.98 × 10^{-3}</td>
<td>9.78 × 10^{-2}</td>
<td>1.95 × 10^{-1}</td>
<td>3.26 × 10^{-2}</td>
<td>9.78 × 10^{-2}</td>
<td>1.95 × 10^{-2}</td>
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<tr>
<td>Hazard</td>
<td>Risk</td>
<td>Consequence</td>
<td></td>
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</tr>
<tr>
<td>Nitrate</td>
<td>Drinking contaminated water</td>
<td>Carcinogenic, teratogenic, mutagenic, E (Rare)</td>
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<tr>
<td>Nitrite</td>
<td>Drinking contaminated water</td>
<td>Carcinogenic, teratogenic, mutagenic, E (Rare)</td>
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<tr>
<td>Manganese</td>
<td>Drinking contaminated water</td>
<td>Tremors, muscle stiffness, and damage to the lungs, liver, and kidneys, E (Rare)</td>
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<tr>
<td>Selenium</td>
<td>Drinking contaminated water</td>
<td>Poisoning (dizziness, nausea, vomiting, and muscle aches), E (Rare)</td>
<td></td>
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<tr>
<td>Chromium</td>
<td>Drinking contaminated water</td>
<td>Carcinogenic, teratogenic, mutagenic, E (Rare)</td>
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<tr>
<td>Cadmium</td>
<td>Drinking contaminated water</td>
<td>Weakness, coughing, shortness of breath, E (Rare)</td>
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<tr>
<td>Flour</td>
<td>Drinking contaminated water</td>
<td>Damage to teeth and bones, E (Rare)</td>
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</tr>
<tr>
<td>Cyanide</td>
<td>Drinking contaminated water</td>
<td>Seizures, difficulty breathing, and cardiac arrest, E (Rare)</td>
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</tbody>
</table>

4 CONCLUSION

The calculation results showed that the concentrations of chemical agents in drinking water found in the Concentrating Division area of PTFI were below the EHQS average stated in the Minister of Health Regulation Number 2 of 2023. Moreover, the EHRA results for the entire chemical agents indicated an RQ<1, leading to their classification as safe or non-risky. This means there is no need for specific risk management and communication. However, routine supervision should be carried out daily to ensure that the chemical agents do not exceed EHQS and remain in compliance with the established provisions.

5 ACKNOWLEDGMENTS

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REFERENCES


