Indonesian Journal of Environmental Management and Sustainability
e-ISSN:2598-6279 *p*-ISSN:2598-6260

Research Paper

Risk Assessment of Chemical Exposure through Consumption of Rainwater in Coastal Areas

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Abstract

Coastal communities rely heavily on Rainwater as their main drinking water source, even though it can be contaminated with harmful chemicals such as nitrates, cadmium, fluoride, and lead. Prolonged exposure to these contaminants poses significant health risks, especially for vulnerable groups such as children and the elderly. This study aims to conduct a comprehensive health risk assessment of chemical exposure through rainwater consumption in coastal populations. An observational-analytical design was used, with the Environmental and Health Risk Assessment framework. The study population was divided into two groups: community and environmental samples. Rainwater samples were collected from eight shelter points, while 94 residents (children and adults) were selected as study subjects. Data collection was carried out through laboratory analysis and structured interviews. The Environmental and Health Risk Assessment methodology is carried out in four stages: hazard identification, dose-response analysis, exposure assessment, and risk characterization. The results showed that the concentration of chemical parameters (NO_3, Cd, Pb, and F) in Rainwater was still within the permissible limits, indicating that Rainwater was relatively safe for consumption. The study provides important insights into the chemical risks associated with Rainwater, offering a foundation for targeted interventions to protect public health, strengthen resilience to environmental hazards, and ensure sustainable management of water resources. The results of the study show that the quality of Rainwater consumed by coastal communities is still within safe limits, but it still needs attention because prolonged exposure has the potential to cause health problems, the study also contributes to the existing literature by integrating chemical risk assessment into public health planning for vulnerable coastal populations, highlighting the importance of proactive risk management strategies in mitigating long-term health impacts.

Keywords

Chemical, Contaminant, Islands, Risk Analysis, Raiwater Harvesting

Received: 01 June 2025, Accepted: 12 March 2026
https://doi.org/10.26554/ijems.2026.10.2.112-119

1. INTRODUCTION

Water is an essential element for the survival of living organisms, and its role cannot be substituted by any other compound (Purwanto, 2021). Therefore, meeting water quality standards for both direct consumption and daily use is crucial for public health (Kementerian Kesehatan Republik Indonesia, 2023). If water fails to meet these standards, it poses health risks, including exposure to diseases caused by microbial contamination, harmful chemicals, or heavy metals. Ensuring that water quality complies with established standards is vital to safeguard both immediate safety and long-term community health (Astuti et al., 2021; Herawati et al., 2024a,b; Kusumawardhana et al., 2021; Mostafaii et al., 2021; Njuguna et al., 2021; Okafor et al., 2023; Romero et al., 2022).

Chronic exposure to waterborne contaminants can lead to serious health issues. Contaminants like heavy metals, pesticides, and pathogenic microorganisms can accumulate in the body over time, significantly increasing the risk of chronic diseases, including neurological disorders, cardiovascular issues, and kidney and liver dysfunction (Dobrinas et al., 2022; Gunjyal et al., 2023; Okafor et al., 2023; Romero et al., 2022). These groups, due to their weakened immune systems, are particularly susceptible to the harmful effects of poor water quality. Therefore, rigorous monitoring of water quality is necessary to safeguard public health (Kementerian Kesehatan Republik Indonesia, 2023; Purwanto, 2021).

The water used to meet daily needs can come from various sources, including surface water (such as rivers, lakes, and reservoirs), groundwater (from shallow and deep wells), and Rainwater collected from rooftops (Sakati et al., 2023).

Each source has its own set of characteristics and potential for contamination (Ghosh et al., 2023; Xu et al., 2022). Surface water is often vulnerable to pollution from domestic, industrial, and agricultural runoff, while groundwater, although generally protected, can still be contaminated by chemicals or heavy metals from human activities or natural geological processes (Deng and Chen, 2022; Esmaeili et al., 2024; Islam et al., 2022; Romero et al., 2022; Smith, 2023).

Rainwater, although inherently purer, can still be contaminated by air pollutants before reaching the ground surface (Chivu et al., 2017; Czerwińska and Wielgosiński, 2019; Yang et al., 2023). Consequently, proper treatment and continuous monitoring of water quality from various sources are crucial to ensure its safety for daily use, including drinking, cooking, bathing, and other purposes (Carpio-Vallejo et al., 2024). In coastal regions, Rainwater is often the primary source of potable water, particularly in areas with limited access to groundwater or proper water distribution systems (United States Environmental Protection Agency, 2012). Rainwater consumed by coastal communities may contain harmful contaminants, including chemicals (Gunjyal et al., 2023; Tenebe et al., 2023). However, there is insufficient data on the extent of chemical contamination in Rainwater, particularly in coastal regions. Coastal populations, including vulnerable groups such as children, face heightened health risks from consuming polluted Rainwater, compounded by limited access to alternative water sources. Consuming contaminated water poses significant health risks.

Coastal communities are heavily reliant on Rainwater as their primary drinking water source. However, chemical contamination in Rainwater presents potential health risks. Coastal regions are also confronted with significant pollution issues stemming from industrial, residential, agricultural, and transportation activities (Contreras et al., 2025; Gunasekara et al., 2025; Jayalath and Ratnayake, 2025). Given these challenges, this study is crucial for risk mitigation, focusing on measuring chemical concentrations in Rainwater and assessing the long-term health impacts of exposure, especially to children. This study aims to evaluate the risk of chemical exposure (NO_3, Cd, Pb, and F) through rainwater consumption among coastal communities. The findings of this study can serve as a foundation for local governments to develop strategies to provide safe water sources for coastal communities, thereby reducing health risks associated with chemical contamination in Rainwater.

2. EXPRIMENTAL SECTION

2.1 Design of Research

This study is an analytical observational research with an Environmental and Health Risk Assessment (EHRA) approach. It is designed to evaluate the health risks faced by populations exposed to chemicals through rainwater consumption, with a particular focus on the specific contaminants found in coastal areas.

2.2 Population and Sample

1. Population
   a. The human population in this study comprised all residents of North Bulagi District, totaling 9,803 individuals.
   b. The environmental population consisted of rainwater sources, specifically all rainwater harvesting and storage systems located within North Bulagi District. These systems were identified and classified based on their geographical distribution and types of storage structures, taking into account the distance between collection points and surrounding environmental characteristics (coastal-residential, residential, low traffic, moderate traffic, and high traffic).
2. Sample
   The sample size for the human population was determined using the Lameshow formula, expressed as follows:

$$n = \frac{Z^2_{1-\alpha/2} \cdot P(1-P) \cdot N}{d^2(N-1) + Z^2_{1-\alpha/2} \cdot P(1-P)}$$

Based on this calculation, 94 respondents were selected. These respondents were divided equally into two groups, consisting of 47 adults and 47 children, to allow for comparative exposure and risk assessment between different age categories. Sampling in this study was conducted using a purposive sampling technique, which selects samples based on specific considerations relevant to the research objectives.

a. Environmental Sample Criteria (Rainwater)
   A total of eight (8) rainwater harvesting and storage units in North Bulagi District were selected as environmental samples using purposive sampling. The selection was based on the following considerations:
   1) Rainwater is widely utilized by the local community as a primary source of clean drinking water.
   2) A high proportion of households depend on Rainwater for daily consumption.
   3) Rainwater catchment systems use metal (zinc) roofing, which may influence water quality.
   4) Sampling locations are situated in areas with high traffic density, increasing the potential for atmospheric pollutant deposition.
   5) Rainwater storage systems are constructed using fiber tanks or concrete structures.

The environmental parameters analyzed in this study included chemical indicators, namely Nitrate (NO_3), Cadmium (Cd), Lead (Pb), and Fluoride (F) in rainwater storage systems.

Rainwater samples were collected using the Integrated Sampling technique, in which samples were collected separately but simultaneously to achieve equal representativeness.

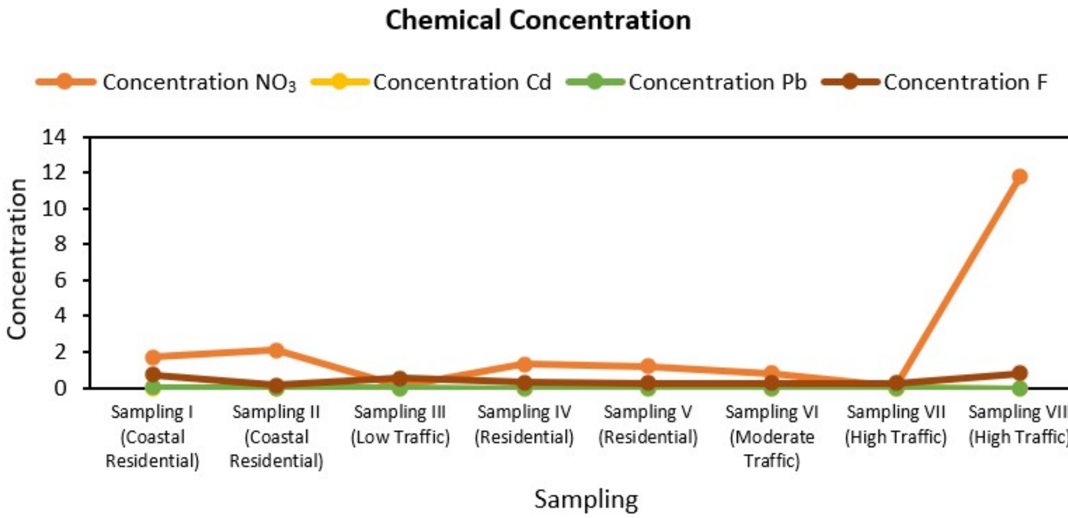

Figure 1. Chemical Concentration

A volume of 100 mL was collected for microbiological analysis, and 2000 mL for chemical analysis, using sterile sampling bottles. All sampling procedures followed the Indonesian National Standard (SNI) for water sampling methods.

b. Human Sample Criteria
   The human samples were divided into two age-based groups: adults and children, with the following inclusion criteria:
   1. Adult Group
      a) Use Rainwater as the primary source of drinking water.
      b) Willing to participate and provide informed consent for the study.
      c) Aged 26-45 years
      d) Have resided in the study area for approximately three years or longer.
   2. Children Group
      a) Use Rainwater as the primary source of drinking water.
      b) Willing to participate with parental or guardian consent.
      c) Aged 11-15 years.
      d) Have attended school in the area for approximately three years, indicating long-term residence and exposure.

2.3 Study Variables

This study measures the concentration of chemical contaminants in Rainwater and evaluates the associated health risks. The environmental variables include the concentration of Nitrate (NO_3), Fluoride (F), Cadmium (Cd), Chromium (Cr), and Lead (Pb) in rainwater samples, while the human population variables are: age, weight, and duration of exposure (length of stay in the coastal area). These variables were chosen to assess both environmental contamination and individual exposure levels

2.4 Data Collection

Data were collected using two primary methods: laboratory analysis and structured interviews. Chemical concentrations in Rainwater were measured using Atomic Absorption Spectrometry (AAS), while data on rainwater consumption behavior were gathered through structured interviews with coastal community members, using questionnaires. The combination of these methods allows for both precise chemical analysis and an understanding of local consumption patterns.

2.5 Data Analysis

The data from laboratory analysis and interviews were analyzed using the Environmental and Health Risk Assessment (EHRA) method, which involves four stages:

1. Hazard Identification
   Hazard identification is a systematic process conducted to determine the presence and concentration of chemical substances that may pose potential risks to human health. This stage aims to identify chemical agents in environmental media that have the potential to cause adverse health effects upon exposure.
2. Dose–Response Analysis
   Dose–response analysis involves determining quantitative toxicity values for each chemical species of the identified risk agents. In this stage, the dose–response relationship is assessed using the oral Reference Dose (RfD), which represents exposure through ingestion.
   The reference dose is not an absolutely safe dose, but rather a guideline value. When the estimated exposure dose exceeds the RfD, the likelihood of adverse health effects increases.
3. Exposure Assessment

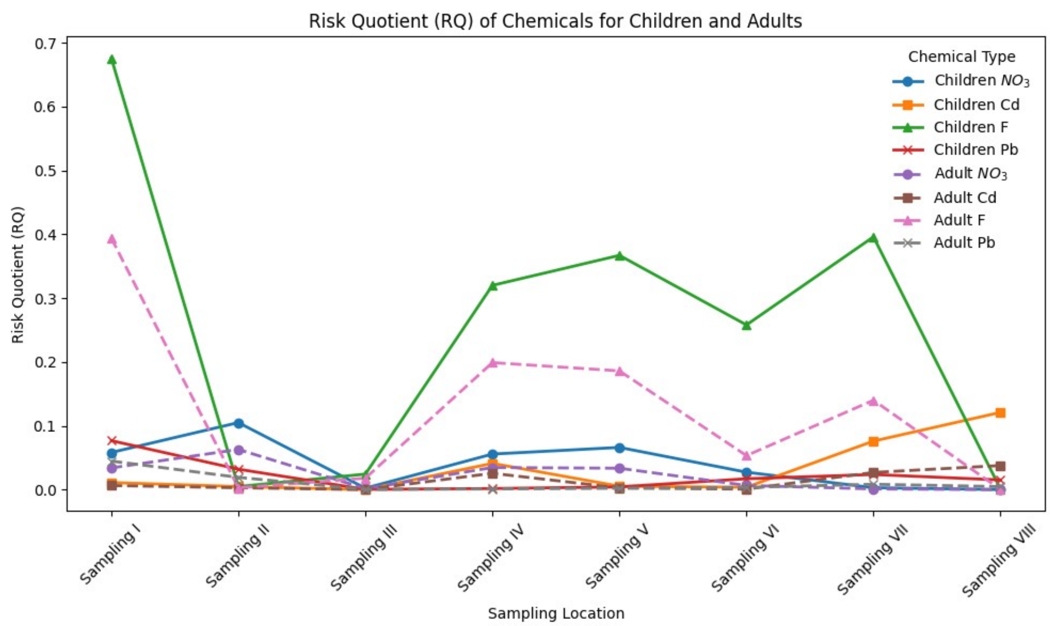

Figure 2. Risk Quotient (RQ)

Exposure is defined as the experience of contact with a chemical agent, foreign substance, or xenobiotic over a specified period at a receptor point. Exposure assessment aims to identify the exposure pathways of risk agents so that the amount of intake received by individuals within the at-risk population can be quantified.

The intake values were calculated using the following equations:

a. Non-carcinogenic Exposure Intake (*Ink*)
Intake through the ingestion pathway:

$$Ink = \frac{C \times R \times f_E \times D_t}{W_b \times t_{AVG}} \quad (1)$$

b. Carcinogenic Exposure Intake (*Ik*)
Intake through the ingestion pathway:

$$Ik = \frac{C \times R \times f_E \times D_t}{W_b \times t_{AVG}} \quad (2)$$

The values of R (intake rate), t_E (exposure time), f_E (annual exposure frequency), D_t (exposure duration), W_b (body weight), and t_{AVG} (averaging time) for both ingestion and inhalation pathways in the simplified EHRA (ARKL) used default values provided by the USEPA. In the complete EHRA framework, data on C, R, t_E, f_E, D_t, and W_b were collected directly from the at-risk population through interviews and field measurements.

4. Risk Characterization
Risk characterization is a qualitative process, and, where possible, a quantitative one, that integrates exposure and toxicity information to estimate the probability of adverse health effects in organisms, systems, or subpopulations, while accounting for uncertainty factors. At this stage, quantitative calculations are performed to determine whether a risk agent at a specific concentration may cause health effects in individuals or populations. Risk characterization is conducted by comparing the calculated intake with the reference dose obtained from the previous calculations.

Risk characterization is divided into two categories:

a. Non-carcinogenic Risk Characterization
Non-carcinogenic risk is expressed as a Risk Quotient (RQ), calculated using the following equation:

$$RQ = \frac{I}{RfD \text{ or } RfC} \quad (3)$$

The risk level is considered acceptable when RQ $\leq$ 1, indicating that the intake does not exceed the reference dose. Conversely, the risk is considered unacceptable when RQ $>$ 1, indicating a potential health risk.

b. Carcinogenic Risk Characterization
Carcinogenic risk is expressed as Excess Cancer Risk (ECR), calculated by multiplying the intake value by the Slope Factor (SF), as shown below:

$$ECR = I \times SF \quad (4)$$

Carcinogenic risk is expressed as a dimensionless probability value. The risk level is considered acceptable when ECR $\leq 10^{-4}$, and unacceptable when ECR $> 10^{-4}$.

Table 1. Dose-Response of Chemical Agent

Chemical Risk Agents	Doses Respon (RfD)	Critical Effects	Reference
Nitrate (NO_3)	1.6 mg/kg/day	Early clinical symptoms of methemoglobinemia	(World Health Organization, 2014)
Cadmium (Cd)	5×10^{-4} mg/kg/day	Proteinuria due to chronic exposure in humans	(World Health Organization, 2014)
Lead (Pb)	4×10^{-3} mg/kg/day	Permanent damage to the brain and nervous system	(World Health Organization, 2014)
Flouride (F)	6×10^{-2} mg/kg/day	Dental milling and cosmetic effects in epidemiologist studies	(World Health Organization, 2014)

Resource: (World Health Organization, 2014)

3. RESULT AND DISCUSSION

3.1 Hazard Identification

The results showed that all chemical parameters (NO_3, Cd, Pb, and F) were within the quality standard limits, which reflected the relatively safe water quality (Figure 1). However, Point VIII stands out with concentrations of NO_3 and F that are close to the threshold, indicating the potential influence of local activities such as heavier traffic.

The results of the study provide empirical data on the exposure of harmful chemicals (Nitrate, Cadmium, Fluoride, Lead) to Rainwater in coastal areas, even though they are present at concentrations still safe for humans. This suggests that although Rainwater naturally tends to be purer, the potential for contamination by harmful chemicals cannot be ignored (Fitria et al., 2018; Konan et al., 2022; Sakati et al., 2024). Pollutants in the atmosphere, such as heavy metals and nitrogen compounds, can be deposited onto the soil surface, increasing the risk of exposure to contaminants. Exposure to these chemicals can cause acute and chronic toxic effects, depending on the type and concentration of the contaminant (Chivu et al., 2017; Czerwińska and Wielgosiński, 2019; Sun et al., 2016; Yang et al., 2023).

Coastal communities use Rainwater as the main source of drinking water. Although Rainwater tends to be purer, the potential for contamination with harmful chemicals cannot be ignored (Tenebe et al., 2023). Atmospheric pollutants, such as heavy metals, can be deposited onto the soil surface, increasing the risk of exposure to contaminants. Exposure to these chemicals can cause health problems, including acute and chronic toxic effects, depending on the type and concentration of the contaminant (El-Aassar et al., 2023). Sources of contamination may include motor vehicle emissions, industrial operations, and other domestic activities. Previous studies conducted in southern Brazil have demonstrated that rainwater contamination is primarily influenced by soil resuspension, traffic-related emissions, and combustion processes, as well as marine aerosols (Hoinaski et al., 2014).

3.2 Dose-Response Analysis

After identifying potential hazards, the next step is to conduct a dose-response analysis to determine the RfD values of the risk agents studied by EHRA, as well as to understand the impact that these agents can have on the human body (Table 1). In EHRA's research on the quality of drinking water sourced from Rainwater in North Bulagi District, Banggai Islands Regency, it was found that chemical parameters such as Nitrate (NO_3), Cadmium (Cd), Lead (Pb), and Fluoride (F) can enter the human body through ingestion routes, with non-carcinogenic properties.

The RfD (Reference Dose) value indicates the daily dose considered safe for humans over a lifetime without significant harmful effects. Excessive exposure to these chemical agents has the potential to cause a variety of serious health problems.

3.3 Intake Rate Analysis

Based on anthropometric data, it is known that in the children's receptor group, the rate of drinking water consumption is 1 liter/day, with a frequency of exposure of 350 days/year, an average body weight of 15 kg, and a duration of exposure for 30 years. Meanwhile, in the adult receptor group, the rate of drinking water consumption reached 2 liters/day, with a frequency of exposure of 350 days/year, an average body weight of 55 kg, and the same duration of exposure (30 years).

The Table 2 presents the results of the calculation of the average intake based on the minimum and maximum concentration ranges of detected chemicals. Nitrate showed the highest value of 2.26×10^{-1} mg/L, followed by Fluoride with a maximum value of 3.893×10^{-2} mg/L. Meanwhile, Cadmium and Lead reached the highest values of 8.545×10^{-6} mg/L and 1.044×10^{-4} mg/L, respectively.

Table 2. Intake Rate

	Intake Rate (mg/L)			
Concentration	I_{nk} Nitrate (NO_3)	I_{nk} Cadmium (Cd)	I_{nk} Fluoride (F)	I_{nk} Lead (Pb)
Min.	5.705×10^{-2}	2.158×10^{-6}	9.829×10^{-3}	2.637×10^{-5}
Max.	2.260×10^{-1}	8.545×10^{-6}	3.893×10^{-2}	1.044×10^{-4}

3.4 Risk Characteristics Analysis

The results of the intake rate calculation are then used to calculate the risk characteristics. Risk characterization is the final stage of the Environmental Health Risk Analysis (EHRA), which aims to determine whether the concentrations of risk agents analyzed have the potential to cause health impacts on the community. This characterization is expressed as a Risk Quotient (RQ), which is used to assess the risk of non-carcinogenic effects. If the RQ > 1, there is a potential health risk, while an RQ ≤ 1 indicates negligible risk (Figure 2).

Variations in RQ values for children and adults based on chemical content (Nitrate, Cadmium, Fluoride, and Lead) at eight sampling points over the next 30 years, fluoride results showed the highest RQ values, especially in children, indicating a greater potential risk compared to other parameters, although still within safe limits. Meanwhile, Nitrate, Cadmium, and Lead have relatively low RQ values, posing less risk to adults than to children. Points 7 and 8 indicate a spike in cadmium risk, so further attention is needed. Using the RQ approach, the study's results project potential long-term health impacts, especially for vulnerable groups, such as children. This provides a clearer understanding of the chronic risks posed by the consumption of polluted Rainwater (Dobrinas et al., 2022; Mostafaii et al., 2021; Okafor et al., 2023; Romero et al., 2022). Although the study results indicate that the chemical indicators in Rainwater are relatively low and still safe for people in coastal areas, management efforts are still needed because there is a risk of long-term consumption (Hooshmandi et al., 2023; Li et al., 2024).

Coastal communities, especially children and vulnerable individuals, face higher health risks from polluted rainwater consumption. This is due to limited access to safer alternative water sources. This condition increases the risk of long-term exposure to harmful chemicals, which can negatively affect the growth, development, and health of the group (Li et al., 2024; Okafor et al., 2023).

The limited data on chemical contamination levels in Rainwater, especially in coastal areas, underscores the urgency of this research. Until now, research mapping specific concentrations of chemicals such as nitrate, cadmium, Fluoride, and lead in Rainwater in coastal areas has been very limited (Astuti et al., 2021; Li et al., 2024; Romero et al., 2022). This information is very important for determining the level of safety of Rainwater consumed by coastal communities, so that the results of the study can serve as a basis for policymakers to design more effective interventions, such as the provision of better water treatment technology or health education programs for coastal communities (Li et al., 2021; Nong et al., 2023; Qi et al., 2023; Tenebe et al., 2023; Urakawa et al., 2022).

Consuming polluted water is known to trigger a variety of health problems, ranging from indigestion to chronic diseases such as kidney damage and nervous system disorders (Purandara et al., 2015; Xu et al., 2022). This risk is even more significant in coastal contexts where communities are heavily dependent on Rainwater without further treatment. Therefore, this study not only aims to fill the data gap but also provides a scientific basis for the development of more effective public health policies and interventions. The construction of Drinking Water Treatment Plants (IPAM) and the periodic monitoring of community drinking water quality can help protect the community from long-term exposure to chemicals.

4. CONCLUSIONS

This study concludes that the chemical indicators in Rainwater remain safe for people in coastal areas. Although the concentrations of chemical parameters have not exceeded the minimum threshold limit, they should be monitored regularly, as they pose potential risks if consumed over the long term. With a better understanding of the chemical risks in Rainwater, we can take strategic steps to protect the health of coastal communities, improve resilience to environmental threats, and ensure the sustainability of water resources. This research paves the way for further studies, including exploring other sources of contamination and the impact of climate change on rainwater quality.

5. ACKNOWLEDGEMENT

We extend our gratitude to the Faculty of Public Health at Tompotika Luwuk University for their support in conducting the research.

REFERENCES

Astuti, R. D. P., A. Mallongi, R. Amiruddin, M. Hatta, and A. U. Rauf (2021). Risk Identification of Heavy Metals in Well Water Surrounds Watershed Area of Pangkajene, Indonesia. *Gaceta Sanitaria*, **35**; S33–S37

Carpio-Vallejo, E., U. Düker, J. Waldowski, and R. Nogueira (2024). Contribution of Rooftop Rainwater Harvesting to Climate Adaptation in the City of Hannover: Water

Quality and Health Issues of Rainwater Storage in Cisterns and Ponds. *International Journal of Hygiene and Environmental Health*, **256**; 114320

Chivu, O. R., A. Semenescu, C. Babis, C. Amza, G. Iacobescu, Z. Apostolescu, V. Petrescu, and G. M. Adir (2017). The Impact of the Industrial Processing of Oil on the Rainfall Water Quality. *Revista de Chimie*, **68**(1); 175–179

Contreras, M., V. Santos Sánchez, J. Alguacil, and R. L. Rodríguez Pacheco (2025). Influence of Phosphogypsum Waste on Rainwater Chemistry in a Highly Polluted Area with High Mortality Rates in Huelva Metropolitan Area, Spain. **7**(17); 3102

Czerwińska, J. and G. Wielgosiński (2019). Changes in the Pollution of Lodz Voivodship Rainwater as a Result of Changes in Pollutant Immissions. *Acta Innovations*, **30**; 31–37

Deng, X. and G. Chen (2022). Characteristics of Water Pollution and Evaluation of Water Quality in Subsidence Water Bodies in Huainan Coal Mining Areas, China. *Journal of Chemistry*, (1); 2857700

Dobrinas, S., A. Soceanu, N. Manea, A. Sirbu, C. I. Dumitrescu, V. Popescu, S. Birghila, N. Matei, and I. C. Popovici (2022). Health Risk Assessment of Fluoride Exposure Due to Groundwater Consumption in Romania. *Journal of Water and Health*, **20**(9); 1380–1392

El-Aassar, A. H. M., R. A. Hussien, F. A. Mohamed, S. Oterkus, and E. Oterkus (2023). Appraisal of Surface-Groundwater Anthropogenic Indicators and Associated Human Health Risk in El Sharqia Governorate, Egypt. *Journal of Water and Health*, **21**(6); 719–739

Esmaeili, R., K. Ebrahimpour, S. V. Esmaeili, A. Karimi, M. Kamranifar, M. N. Pour, and H. Ebrahimi (2024). Chemical Health Risk Assessment of Exposure to Metal Fumes among Employed Workers in a Metal Manufactory with an Electric Arc Furnace. *International Journal of Environmental Health Engineering*, **13**(5); 18

Fitria, D. Sutjiningsih, and T. Siswantining (2018). The Modelling Study of Well Water Quality in Urban Area (a Literature Study). In *AIP Conference Proceedings*, volume 1977. AIP Publishing LLC, page 050004

Ghosh, G. C., T. K. Chakraborty, N. Shekder, T. A. Tanin, A. Habib, and S. Zaman (2023). Groundwater Quality and Human Health Risk Assessment in Urban and Peri-Urban Regions of Jashore, Bangladesh. *H2Open Journal*, **6**(4); 576–587

Gunasekara, M. I., I. Mahawaththa, D. Madhubhashini, and K. Amarasena (2025). Pollution from Land-Based Sources: Industrial and Urban Runoff. *Coastal and marine pollution: source to sink, mitigation and management*, (1); 27–44

Gunjyal, N., S. Rani, B. Asgari Lajayer, V. Senapathi, and T. Astatkie (2023). A Review of the Effects of Environmental Hazards on Humans, Their Remediation for Sustainable Development, and Risk Assessment. *Environmental Monitoring and Assessment*, **195**(6); 795

Herawati, M. Syahrir, Yusuf, S. N. Sakati, and D. W. Balebu (2024a). Assessing Groundwater Quality in Rural Communities: A Detailed Study of Physical, Chemical, and Microbial Contaminant. *International Journal of Medical Toxicology and Legal Medicine*, **27**(1); 180–188

Herawati, H., M. Kanan, A. Mallongi, R. Bidullah, S. N. Sakati, and D. W. Balebu (2024b). Risk Analysis of Groundwater Contaminant in Rural Areas Using Spatial Distribution. *Journal of Public Health and Pharmacy*, **4**(3); 214–224

Hoinaski, L., D. Franco, R. Haas, R. F. Martins, and H. D. M. Lisboa (2014). Investigation of Rainwater Contamination Sources in the Southern Part of Brazil. *Environmental Technology*, **35**(7); 868–881

Hooshmandi, M., A. M. Tehrani, M. H. Mohraz, M. Leili, and M. J. Assari (2023). Evaluation of Seasonal Variation on the Health Risks Using the Quantitative Microbial Risk Assessment Approach in a Wastewater Treatment Plant in Hamadan, Iran. *Journal of Research in Health Sciences*, **23**(1); 1–7

Islam, M. S., K. Nakagawa, M. Abdullah-Al-Mamun, A. S. Khan, M. A. Goni, and R. Berndtsson (2022). Spatial Distribution and Source Identification of Water Quality Parameters of an Industrial Seaport Riverbank Area in Bangladesh. *Water*, **14**(9); 1356

Jayalath, G. N. T. and A. S. Ratnayake (2025). Overview of Coastal and Marine Pollution: Sources, Impacts, and Challenges. *Coastal and marine pollution: Source to sink, mitigation and management*; 1–25

Kementerian Kesehatan Republik Indonesia (2023). Laporan Tahunan: Pengamanan Kualitas Air Minum Tahun 2022. (in Indonesia)

Konan, B. R., V. Yoboue, B. Adiaffi, M. Diaby, Y. M. S. Oga, A. Bakayoko, S. Gnamien, S. Keita, J. Bahino, and M. Ossohou (2022). Source of Polycyclic Aromatic Hydrocarbons (PAHs) in Rainwater and Effect on the Health of the Population: the Case of the District of Abidjan in the South of Ivory Coast. *Journal of Water and Health*, **20**(6); 985–1004

Kusumawardhana, A., L. Zlatanovic, A. Bosch, and J. P. van der Hoek (2021). Microbiological Health Risk Assessment of Water Conservation Strategies: A Case Study in Amsterdam. *International Journal of Environmental Research and Public Health*, **18**(5); 1–17

Li, P., T. Wu, G. Jiang, L. Pu, Y. Li, J. Zhang, F. Xu, and X. Xie (2021). An Integrated Approach for Source Apportionment and Health Risk Assessment of Heavy Metals in Subtropical Agricultural Soils, Eastern China. *Land*, **10**(10); 1016

Li, T., J. Bian, D. Ruan, L. Xu, and S. Zhang (2024). Groundwater Health Risk Assessment and Its Temporal and Spatial Evolution Based on Trapezoidal Fuzzy Number–Monte Carlo Stochastic Simulation: A Case Study in Western Jilin Province. *Ecotoxicology and Envi-*

ronmental Safety, **282**; 116736

Mostafaii, G. R., Z. Bakhtyari, F. Atoof, M. Baziar, R. Fouladi-Fard, M. Rezaali, and N. Mirzaei (2021). Health Risk Assessment and Source Apportionment of Heavy Metals in Atmospheric Dustfall in a City of Khuzestan Province, Iran. *Journal of Environmental Health Science and Engineering*, **19**(1); 585–601

Njuguna, S. M., K. B. Githaiga, J. A. Onyango, R. W. Gituru, and X. Yan (2021). Ecological and Health Risk Assessment of Potentially Toxic Elements in Ewaso Nyiro River Surface Water, Kenya. *SN Applied Sciences*, **3**(2); 1–11

Nong, X., X. Yi, L. Chen, D. Shao, and C. Zhang (2023). Impact of Inter-Basin Water Diversion Project Operation on Water Quality Variations of Hanjiang River, China. *Frontiers in Ecology and Evolution*, **11**; 1159187

Okafor, V. N., D. O. Omokpariola, O. F. Obumselu, and C. G. Eze (2023). Exposure Risk to Heavy Metals Through Surface and Groundwater Used for Drinking and Household Activities in Ifite Ogwari, Southeastern Nigeria. *Applied Water Science*, **13**(4); 1–20

Purandara, B. K., T. Chandramohan, M. K. Jose, and B. Venkatesh (2015). Groundwater Quality Investigations and Modeling in Bhadravathi Town, Karnataka. *International Journal of Engineering Research and Technology*, **3**(3); 1–6

Purwanto, M. (2021). Karakteristik Air Baku dan Analisis Pengelolaan Sumber Air pada Skala Rumah Tangga. (in Indonesia)

Qi, M., Y. Wu, S. Zhang, G. Li, and T. An (2023). Pollution Profiles, Source Identification and Health Risk Assessment of Heavy Metals in Soil near a Non-Ferrous Metal Smelting Plant. *International Journal of Environmental Research and Public Health*, **20**(2); 1004

Romero, C. M., C. A. Ucán, A. S. Peralta, J. T. Reyes, Y. C. López, V. C. Quiroz, and A. R. Marín (2022). Health Risk Assessment of Heavy Metals: Cu, Cd, Pb, Ni and Hg in Catfish *Ariopsis felis* in Southern Mexico. *Iranian Journal of Toxicology*, **16**(3); 163–174

Sakati, S. N., A. Mallongi, E. Ibrahim, H. Amqam, and M. Kanan (2024). Microbiological Exposure Risk Assessment in Rainwater Harvesting Systems: Implications for Community Health. *International Journal of Medical Toxicology and Legal Medicine*, **27**(2); 278–285

Sakati, S. N., A. Mallongi, E. Ibrahim, Budimawan, Stang, S. Palutturi, M. Kanan, and Herawati (2023). Utilization of Rainwater as Consumable Water with Rainwater Harvesting Methods: A Literature Review. *Pharmacognosy Journal*, **15**(6); 1254–1257

Smith, I. (2023). Water Pollution and Cancer: An Updated Review. *Science Insights*, **43**(4); 1079–1086

Sun, T., M. Ma, and D. Y. Wang (2016). Interceptive Characteristics of Lead and Cadmium in a Representative Forest Ecosystem in Mid-Subtropical Area in China. *Shengtai Xuebao*, **36**(1); 218–225

Tenebe, I. T., E. O. Babatunde, J. B. Neris, C. Mikano, O. B. Ezeudu, O. C. Edo, O. H. Fred-Ahmadu, C. D. Chukwuka, and N. U. Benson (2023). Reliability of Stored River Water as an Alternative for Consumption in Ekpoma, Nigeria: A Human Health Risk Assessment. *Journal of Water and Health*, **21**(5); 571–585

United States Environmental Protection Agency (2012). Recreational Water Quality Criteria. Issue December

Urakawa, H., M. A. Kratz, T. L. Hancock, and R. A. Armstrong (2022). QT-AMP: Sequencing PCR Amplicons from Quanti-Tray Wells to Analyze Enterococci Communities. *Science of the Total Environment*, **839**; 156188

World Health Organization (2014). *Water Safety in Distribution System*. World Health Organization

Xu, M., K. Zhang, Y. Wang, B. Zhang, K. Mao, and H. Zhang (2022). Health Risk Assessments and Microbial Community Analyses of Groundwater from a Heavy Metal-Contaminated Site in Hezhou City, Southwest China. *International Journal of Environmental Research and Public Health*, **20**(1); 604

Yang, H. C., M. Jusoh, Z. Y. Zakaria, and A. Rosli (2023). Rainwater to Potable Water: Mini Review. *Chemical Engineering Transactions*, **106**; 775–780

