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Ammonia Exposure Risk Analysis for Mothers and Children at Tamangapa Landfill, Makassar

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Abstract

Ammonia (NH_3) is a toxic compound produced from the anaerobic decomposition of organic waste in landfill sites. Chronic exposure through contaminated groundwater poses significant health risks, particularly for vulnerable groups such as mothers and children. This study assessed ammonia concentrations in dug well water and evaluated non-carcinogenic health risks among residents near the Tamangapa Landfill in Makassar City, Indonesia. Using an Environmental Health Risk Assessment (EHRA) approach, 38 water samples were collected from wells in four cardinal directions around the landfill. Ammonia levels were analyzed via the potentiometric method. Results showed that most samples exceeded the Indonesian clean water standard of 0.10 mg/L, with concentrations ranging from 0.08 to 0.27 mg/L (mean: 0.19 mg/L). Health risk was quantified using Average Daily Dose (ADD) and Target Hazard Quotient (THQ) for ingestion and dermal exposure pathways. Although THQ values were generally below 1—indicating low immediate risk—several locations recorded values approaching or exceeding the threshold, especially among children, who are more susceptible due to lower body weight and higher metabolic rates. These findings highlight the urgent need for improved leachate management and a transition from open dumping to a sanitary landfill system. Community-based interventions, including environmental health education and access to safe drinking water, are also recommended to reduce long-term exposure and protect sensitive populations

Introduction

Environmental pollution caused by human activities is a public health problem that continues to rise in various parts of the world, particularly in developing countries. One form of environmental pollution that significantly impacts human health is groundwater pollution caused by waste management activities that do not comply with environmental health standards (Shetty *et al.*, 2023; Siddiqua *et al.*, 2022). Contaminated groundwater can serve as a medium for the transfer of various hazardous chemicals to the human body, either directly through drinking water consumption or indirectly through the use of water for daily household activities (Lin *et al.*, 2022; Yu *et al.*, 2020).

Ammonia (NH_3) is a chemical commonly found around landfill sites. This substance is derived from the decomposition of organic matter, such as food scraps and domestic waste, by anaerobic microorganisms in garbage piles. Ammonia is toxic, highly soluble in water, and can seep into soil layers, contaminating groundwater sources (Faraday *et al.*, 2024; Ding *et al.*, 2021). At low levels, ammonia produces a pungent odor and discomfort; however, at high levels and with chronic exposure, this compound can cause serious health effects, such as respiratory irritation, digestive system disorders, and liver and kidney damage(Li & Srinivasamoorthy, 2021; Suryadi *et al.*, 2021).

The World Health Organization (WHO) stipulates that the concentration of ammonia in

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drinking water should not exceed 0.10 mg/L, because levels above this value can cause health problems if consumed continuously, particularly gastrointestinal irritation, disruption of nitrogen metabolism, and potential damage to the liver and kidneys, especially in vulnerable populations such as children and pregnant women. In addition, elevated ammonia levels may indicate contamination from organic waste or agricultural runoff, reflecting poor water quality and increasing the risk of secondary health effects due to the presence of other harmful contaminants and pathogens in the water. Prolonged exposure to ammonia-contaminated water may also compromise the palatability of drinking water, leading to reduced consumption and indirect effects on hydration status and overall health (Lukiyono *et al*., 2023). However, a report from the Agency for Toxic Substances and Disease Registry (ATSDR) states that long-term exposure to ammonia can lead to changes in the body's acid–base balance as well as metabolic disorders (Sakunkoo *et al*, 2022).

This situation is becoming more concerning in Indonesia, considering that most landfills still use the open dumping system, which involves piling up waste on the ground without protective layers and a proper leachate management system to manage the waste. This system causes leachate containing ammonia and other pollutants to seep into the soil and contaminate the groundwater source (Maliga *et al*., 2025). Landfills are final disposal sites for waste generated from various sources, including households, markets, industries, and commercial areas. Field observations at the Tamangapa Landfill revealed the presence of mixed waste, including hazardous materials such as batteries, paint containers, light bulbs, and electronic components (e.g., telephones, power and Internet cables, LED and emergency lights). The site is actively frequented by informal waste pickers who work 8–9 hours per day sorting recyclables, often alongside roaming livestock, particularly cows. These activities, combined with the daily entry of approximately 281 waste transport vehicles between 6:00 a.m. and 5:00 p.m., generate significant airborne dust, contributing to environmental degradation and potential health risks for workers and nearby residents Abidin *et al*., 2023). According to data from the Ministry of Environment and Forestry (2021), of the more than 500 landfills operating in Indonesia, approximately 70% still use the open dumping method, including the Tamangapa Landfill in Makassar City Faraday *et al*., 2024).

Tamangapa Landfill is the largest final disposal site in Makassar City, receiving more than 800 tons of waste every day. The natural decomposition of waste at this site produces dark black leachate with a high ammonia content. Several studies have indicated that ammonia levels in the wells of residents around the Tamangapa Landfill exceed clean water quality standards. Research found an average ammonia concentration of 0.23 mg/L in residents' wells located less than 200 m from the landfill (Abidin *et al*., 2024). This value indicates that the well water in the area has been contaminated with ammonia and has the potential to pose health risks, especially to vulnerable groups such as mothers and children.

Mothers and children are among the most sensitive groups exposed to environmental chemicals. Children have lower body weights and higher metabolic rates than adults; therefore, the exposure dose per kilogram of body weight will be greater. Meanwhile, for mothers, especially pregnant and breastfeeding mothers, exposure to toxic substances can affect the development of the fetus and babies (Nursanti *et al*., 2025). Therefore, health risk assessment in this group is very important to determine the extent to which ammonia exposure can cause long-term health effects. The Environmental Health Risk Assessment (EHRA) approach is a scientific method used to measure the potential health risks associated with exposure to hazardous substances in the environment. This approach involves four main stages: hazard identification, dose-response assessment, exposure assessment, and risk characterization. The results of the analysis, presented as the Average Daily Dose (ADD) and Target Hazard Quotient (THQ) values, were used to determine the level of exposure hazard to a specific population's public health (Nong *et al*., 2024), while a THQ value < 1 signifies that the exposure is still within safe limits.

Several studies related to the risk of

ammonia exposure in landfill areas have been conducted in various regions, such as the Jatibarang Semarang Landfill and the Suwung Denpasar Landfill, which show a relationship between the distance of wells and ammonia levels, as well as an increased potential health risk at distances less than 200 m from the pollution source (Lukiyono *et al*., 2023). However, research specifically assessing the health risks associated with ammonia exposure for mothers and children in the Tamangapa Landfill area of Makassar City is still limited. Considering the data and environmental issues described above, the phenomenon of groundwater pollution due to waste disposal activities in the Tamangapa Landfill area of Makassar City is an environmental health issue that is very important to study in depth. The increase in ammonia levels in residents' well water used for daily needs indicates a potential threat to public health, especially for vulnerable groups such as mothers and children, who have higher sensitivity to chemical exposure. Using the Environmental Health Risk Assessment (EHRA) approach, a quantitative assessment of the health risks posed by ammonia exposure can be conducted through both ingestion and dermal routes. This approach not only provides an overview of the magnitude of the risk faced by the community but can also serve as a scientific basis for developing mitigation strategies, such as improving leachate management systems, implementing sanitary landfill technologies, and providing safe drinking water for communities surrounding the landfill. Based on this description, the researcher is interested in conducting a study titled: "Environmental Health Risk Analysis of Ammonia Exposure in Mothers and Children in the Tamangapa Landfill Area, Makassar City."

Method

This study used a quantitative method with an Environmental Health Risk Assessment (EHRA) approach and a cross-sectional study design. This approach allows for a direct assessment of the relationship between ammonia levels in well water and the health risks to mothers and children around the Tamangapa Landfill area in Makassar City. This method was chosen because it can provide a quantitative overview of the level of exposure to hazardous chemicals through ingestion and dermal routes and identify the magnitude of non-carcinogenic risks that may be posed by ammonia. The population in this study included all households residing around the Tamangapa landfill area within a distance of 100–500 m from the waste disposal site and using dug well water as their main water source. The study sample consisted of a portion of households that met the inclusion criteria, namely those willing to participate as respondents, using well water for domestic needs, and having family members in the mother and child category who were potentially exposed to contaminated water.

The sampling technique was carried out using the purposive sampling method, which is the selection of sampling points based on the criteria of distance from the pollution source and the direction of the groundwater flow. Water samples were collected from 38 dug wells owned by residents in four cardinal directions (north, south, east, and west) at varying distances from the landfill. Samples were collected using sterile containers at a minimum depth of one meter from the water surface, stored in sealed containers, and cooled before being analyzed in the laboratory. The sample collection locations are shown in Figure 1. Health Risk Assessment (HRA) is a systematic approach used to estimate the potential adverse health effects in humans resulting from exposure to environmental contaminants. In this study, HRA was applied to evaluate the non-carcinogenic health risks associated with ammonia (NH_3) exposure through the ingestion pathway among mothers and children living around the Tamangapa landfill area in Makassar City.

The assessment focused on oral exposure to ammonia-contaminated environmental media, particularly drinking water and household water sources, which represent the most relevant exposure pathways for mothers and children in residential areas adjacent to landfill sites. The HRA framework followed the Environmental Health Risk Analysis (ARKL) approach, which is commonly applied in Indonesia, and was aligned with international guidance from the United States Environmental Protection Agency (USEPA).

Exposure assessment aims to quantify the amount of ammonia entering the human body through ingestion. The intake dose (Intake_ing) of ammonia via the ingestion pathway was calculated using the following equation:

$$Intake\ Ingesti = \frac{C \ x\ IR\ x\ EF\ x\ ED}{WB\ x\ AT}$$

Where:
C = Ammonia concentration in water (mg/L)
IR = Ingestion rate (L/day)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)
AT = ED × 365 days (for non-carcinogenic risk)

The ingestion rate and body weight values were differentiated between mothers and children based on the ARKL and USEPA Exposure Factors Handbook guidelines. Data on exposure duration and daily water consumption were obtained using structured questionnaires administered to the study participants. The potential non-carcinogenic health risk from ammonia ingestion was evaluated using the Hazard Quotient (HQ) approach. THQ was calculated as follows:

$$THQ = \frac{Intake\ Ingesti}{Rfd}$$

Where:
Intake_ing = Daily intake of ammonia via ingestion (mg/kg/day)
RfD = Reference dose for ammonia (mg/kg/day)

The reference dose (RfD) represents the maximum acceptable oral exposure level that is unlikely to cause adverse health effects over a lifetime. According to USEPA guidelines, THQ values < 1 indicate no significant health risk, whereas THQ values ≥ 1 suggest potential non-carcinogenic health effects. Risk estimates were calculated separately for mothers and children to account for differences in body weight, ingestion rate, and vulnerability. Children are considered a sensitive population due to their lower body weight and higher intake per unit body mass. The calculated THQ values were interpreted to determine whether ammonia exposure through ingestion poses a potential health concern for residents living near the Tamangapa landfill.

Table 1 shows the parameters used for Health Risk Assessment (HRA). resulting from

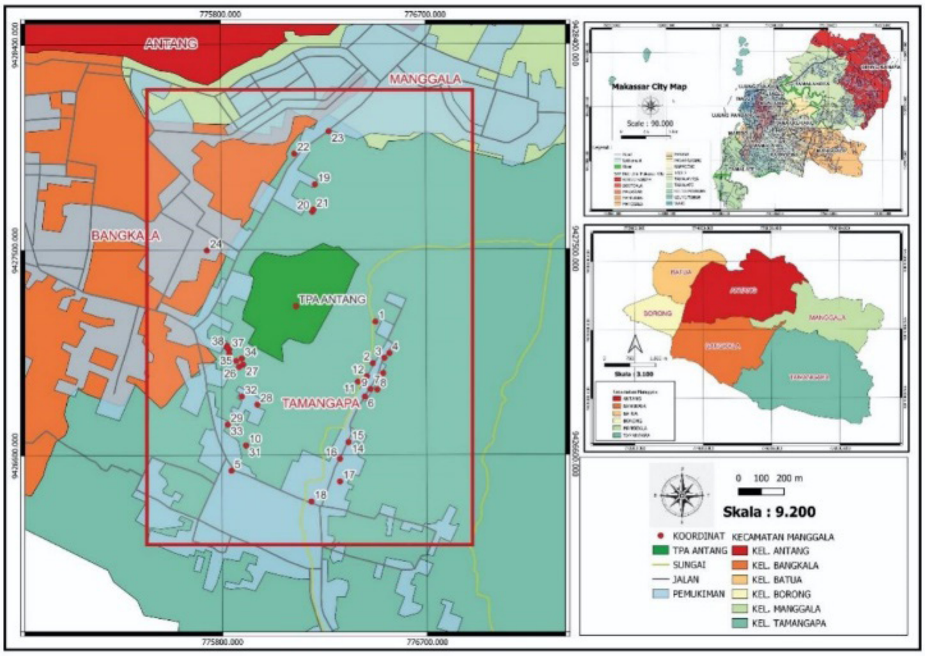

Figure 1. Overview of Sample Collection Location Points

inhalation exposure have been calculated as follows:

Result and Discussion

The results were obtained based on the research conducted. Based on Figure 2, the results of ammonia level tests in clean water samples (well water and borehole water) in the Tamangapa area show that the highest nitrate concentrations were found near the Tamangapa landfill. Specifically, point 1 was to the east, points 20 and 21 were to the north, point 24 was to the west, and points 34 to 38 were to the south. Based on these results, several points exceed the ammonia quality standard set by the Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2023 concerning Environmental Health, which is 0.10 ml/l.Indonesia Number 2 of 2023 concerning Environmental Health, which is 0.10 ml/l.

The data in Table 1 shows that the number of female respondents is higher than that of male respondents, with the most common age range being 6-19 years old, totaling 23 respondents. In terms of occupation, the respondents are mostly housewives, with 21 respondents, and the most common weight category is over 61 kg, with 20 respondents.

Table 2 shows that the body weight of respondents in this study varied widely, ranging from 3 kg to 85 kg, with an average value of 39.6

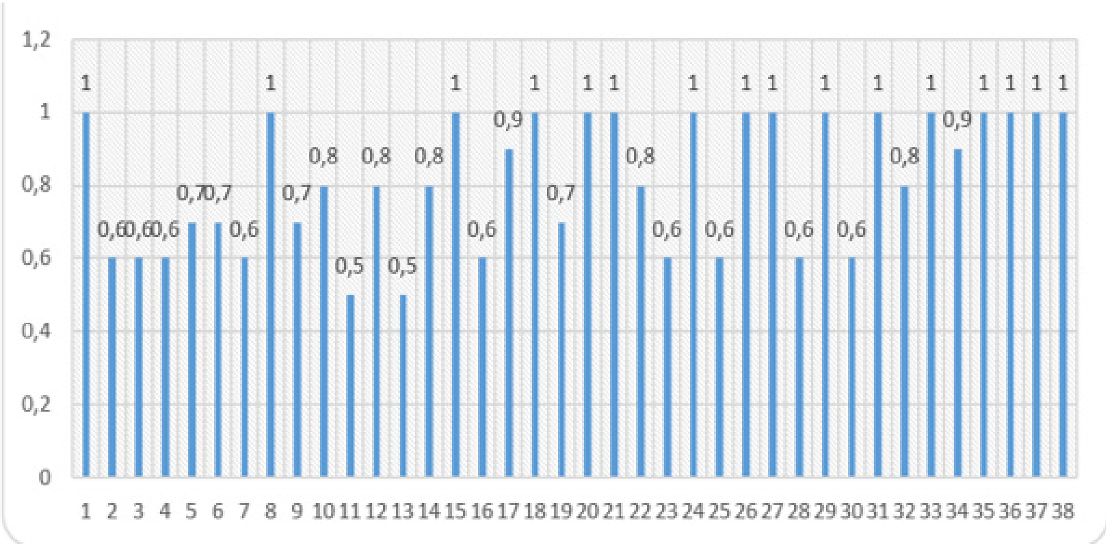

Figure 2. Graph Concentrations of Ammonia

Table 1. Distribution of Respondent Characteristics in the Tamangapa Landfill Area (n=76)

Variable	n	%
Age (Year)		
< 5	16	21,05
6-19	23	30,26
20-33	10	13,16
33-46	7	9,21
47-60	14	18,42
60	6	7,89
Job		
Laborer	2	2,63
House Wife	21	27,63
Trader	1	1,32

Scavenger	1	1,32
Farmer	1	1,32
Enterpreuner	10	13,16
Student	19	25,00
Does not work	21	27,63
Body Weight (kg)		
< 10	5	6,58
10-20	19	25,00
21-30	11	14,47
30-40	5	6,58
41-50	7	9,21
51-60	9	11,84

Table 2. Characteristics of Respondents Based on Body Weight and Activity Patterns of the Community Around the Tamangapa Landfill Area.

Indicator	Min	Max	Mean	Information
Body Weight (WB)	3	85	39.6	kg
Intake Rate (IR)	1	2	1.5	l/day
Exposure Duration (ED)	12	67	38.3	year
Average Time (AT)	2190	10950	6570	day
Exposure Frequency (EF)	356	356	356	day/year

Table 3. Minimum, Maximum, and Mean ADD Values of Respondents for Ammonia Exposure via Ingestion Around the Tamangapa Landfill Area.

Intake (ml/L/Day)	Min		Max		Mean	
	Children	Adult	Children	Adult	Children	Adult
Real Time	1×10^{-2}	2×10^{-1}	1×10^{-1}	1×10	7×10^{-2}	5×10^{-1}
Life Time						
5	5×10^{-2}	1×10	8×10^{-1}	8×10	3×10^{-1}	2×10
10	1×10^{-1}	2×10	1×10	1×10	7×10^{-1}	5×10
15	1×10^{-1}	3×10	1×10	2×10	1×10	7×10
20	2×10^{-1}	4×10	1×10	3×10	1×10	1×10
25	2×10^{-1}	6×10	1×10	4×10	1×10	1×10
30	3×10^{-1}	7×10	1×10	5×10	2×10	1×10

kg. This wide range of body weight indicates the diversity of demographic characteristics of the respondents involved in the study, which likely includes various age groups, from toddlers to adults.

Based on Table 3, the real-time non-carcinogenic ADD intake of ammonia exposure through the ingestion (oral) route for 76 respondents showed that the mean value for adults of 5 x 10^-1 is higher compared to children, which is 7 x 10^-2. Meanwhile, the projected lifetime non-carcinogenic ADD intake of ammonia exposure for years 5–30 shows that the mean value for children, 3 x 10^-1 - 2 x 10 ml/L/day, is lower compared to adults, which is 2 x 10 - 1 x 10^1 ml/L/day.

Based on Table 4, it can be seen that the real-time non-carcinogenic target

Table 4. Minimum, Maximum, and Mean THQ Values of Ammonia via Ingestion Pathway Around the Tamangapa Landfill Area.

Intake (ml/L/Day)	Min		Max		Mean		Descriptions	
	Children	Adult	Children	Adult	Children	Adult	Children	Adult
Real Time	1×10^5	7×10^7	2×10^5	5×10^8	8×10^5	1×10^8	Risk	Risk
Life Time								
5	6×10^5	3×10^6	1×10^7	2×10^9	4×10^6	7×10^8	Risk	Risk
10	1×10^6	7×10^6	2×10^7	5×10^9	8×10^6	1×10^9	Risk	Risk
15	2×10^6	1×10^9	3×10^7	7×10^9	1×10^7	2×10^9	Risk	Risk
20	2×10^6	1×10^9	4×10^7	1×10^{10}	1×10^7	3×10^9	Risk	Risk
25	3×10^6	1×10^9	5×10^7	1×10^{10}	2×10^7	3×10^9	Risk	Risk
30	4×10^6	2×10^9	6×10^7	1×10^{10}	2×10^7	4×10^9	Risk	Risk

hazard quotient (THQ) of ammonia for 76 respondents (children and adults) shows that the mean value for adults is 1 x 10^8, which is higher compared to children at 8 x 10^5. This indicates that the average population around the Tamangapa landfill area is at risk of health disorders for both children and adults since the THQ value is greater than 1. Meanwhile, the projected lifetime THQ for years 5 - 30 is around 4 x 10^6 – 2 x 10^7 for children and about 7 x 10^8 – 4 x 10^9 for adults, so it can be concluded that over a lifetime of 5 – 30 years, the population around the Tamangapa landfill area is at risk of experiencing health disorders. Ammonia contamination in groundwater is an environmental health threat commonly found in areas around landfill sites, particularly in open-dumping waste management systems, such as the Tamangapa Landfill in Makassar City. Research results show that the ammonia (NH_3) levels in dug wells in the area range from 0.08–0.27 mg/L, with an average of 0.19 mg/L. This value exceeds the safe threshold of 0.10 mg/L set by the Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023, indicating potential contamination of groundwater by organic waste decomposition activities (Keithley *et al.*, 2021).

Ammonia is produced through the decomposition of proteins and urea from organic materials that accumulate in landfills. In an open waste management system without a protective liner, the resulting leachate has a high potential to seep into the soil and contaminate the surrounding aquifers (Trach *et al.*, 2024). revealed that landfill leachate contains high concentrations of ammonia, which can directly impact groundwater quality (Okyere *et al.*, 2025). The conditions at the Tamangapa landfill align with this phenomenon, where most water samples within a radius of <200 m from the landfill site showed the highest ammonia levels, indicating a significant relationship between distance and groundwater pollution levels (Suaebu *et al.*, 2025).

Non-carcinogenic health risk analysis through calculations showed THQ values of 0.07–0.24 for children and 0.05–0.16 for mothers. Although the overall THQ values remained below the threshold of 1, indicating a low risk in the short term, several sampling points, particularly those located less than 200 m from the pollution source, exhibited THQ values approaching 1. This suggests that potential health risks should persist chronically over the long term. Notably, children demonstrated relatively higher THQ values than adults at identical locations, reflecting this group's specific vulnerability to ammonia exposure (Nong *et al.*, 2024). However, THQ values approaching one at several sampling points indicate a potential risk of chronic exposure. This condition is consistent with the findings of those who found a trend of increased health risks among residents living within a radius of less than 200 m from the Tamangapa landfill (Siddiqua *et al.*, 2022).

Several environmental factors contribute to ammonia contamination in the study area. The main factors are the open-dumping waste management system, inadequate drainage, and permeable soil characteristics that accelerate leachate infiltration into the aquifer layers (Mihai *et al.*, 2022; Sarles *et al.*, 2024). In addition, high rainfall in Makassar City increases the volume of leachate formed, and a 10% increase in rainfall could increase the ammonia content in groundwater by up to 25% due to more intensive infiltration (Gunarathne *et al.*, 2024; Suaebu *et al.*, 2025).

For mothers, particularly those who are pregnant or lactating, ammonia exposure presents dual risks. First, ammonia entering the maternal bloodstream can disrupt the acid-base balance and nitrogen metabolism, adversely affecting maternal health through gastrointestinal irritation and reduced renal function. During pregnancy, ammonia can cross the placental barrier and affect fetal development because the fetal detoxification system remains immature. Disrupted nitrogen metabolism in the fetus may impair protein synthesis, which is critical for organ and tissue development during lactation. Although direct ammonia transfer through breast milk is relatively low, chronic maternal exposure may indirectly affect the quality and nutritional composition of breast milk through systemic metabolic disturbances in the mother (Lin *et al.*, 2022; Vaverková *et al.*, 2018). Children's heightened vulnerability to ammonia exposure can be explained by three primary physiological mechanisms. First, children's lower body weight results in a higher exposure dose per kilogram of body weight (Average Daily Dose/ADD), even when consuming the same water volume as adults. Second, children's metabolic and detoxification systems remain underdeveloped, limiting their capacity to process and eliminate toxic compounds, such as ammonia (Ding *et al.*, 2021; Gumede & Gumede , 2025.).

Efforts to control environmental health risks in the Tamangapa landfill area must be directed towards implementing a sanitary landfill system to prevent leachate from seeping into the soil and groundwater. This technology uses a protective layer (geomembrane) and an integrated leachate collection system, which can reduce groundwater contamination by up to 80%. In addition, regular monitoring of groundwater quality within a 500-meter radius of the landfill is important for the early detection of potential pollution (Okyere *et al.*, 2025). It is important to note that although the current non-carcinogenic risks are classified as low (THQ < 1), a cumulative risk assessment approach should be considered. Groundwater contaminated with ammonia often contains additional contaminants such as nitrates, heavy metals, and pathogens originating from landfill leachate (Rivai *et al.*, 2024; Suryadi *et al.*, 2025; Abidin *et al.*, 2023) Simultaneous exposure to multiple contaminants may produce synergistic effects that substantially increase overall health risks, particularly for vulnerable populations such as mothers and children. Furthermore, long-term exposure to sub-clinical ammonia levels may induce physiological adaptations that ultimately reduce functional reserves of vital organs, thereby increasing susceptibility to degenerative diseases in adulthood (Siddiqua *et al.*, 2022).

Community empowerment also plays an important role in risk management. Environmental health education regarding the dangers of ammonia-contaminated water and proper clean water usage behavior needs to be improved, especially among housewives. This program can be integrated into environmental cadres, community health posts, and elementary schools to raise awareness and promote hygienic behavior among the local community. States that changing community behavior through an educational, participatory approach is an effective strategy to reduce the risk of diseases caused by environmental factors (Armocida *et al.*, 2022; Aprilyani *et al.*, 2025).

Local governments are expected to strengthen cross-sector collaboration between the Environmental Agency, Health Department, and educational institutions in monitoring water quality and managing pollution based on community involvement. The Community-Based Environmental Monitoring (CBEM) program initiated by the USEPA can be adapted for local implementation in the context of the Tamangapa Landfill (Asyura *et al.*, 2025). With this approach, the community can directly participate in monitoring water quality and in early reporting if pollution occurs (Choi *et al.*, 2025). Overall, the results of this study indicate that ammonia exposure in the Tamangapa landfill area is still in the low-risk category but has the potential to increase if waste management systems are not improved in the future. Mitigation efforts through technical control, public education, and continuous environmental monitoring are important steps in preventing long-term health impacts, especially in mothers and children, who are most vulnerable to exposure to environmental chemicals.

Conclusion

Groundwater around Tamangapa Landfill is contaminated with ammonia (0.08–0.27 mg/L; mean 0.19 mg/L), exceeding Indonesia's standard of 0.10 mg/L. Although current non-carcinogenic health risks remain below the threshold of concern (THQ < 1) for both children (0.07–0.24) and mothers (0.05–0.16), the highest risks occur within 200 meters of the landfill, with children showing greater vulnerability due to lower body weight and immature detoxification systems. Chronic exposure poses concerns for mothers and children: ammonia may impair fetal development during pregnancy, disrupt maternal metabolism, and affect children's neurodevelopment and organ function over time. Cumulative exposure to multiple leachate contaminants may further elevate health risks. Urgent interventions are needed: (1) provide safe alternative water sources for households within 500 meters of the landfill, prioritizing families with young children and pregnant/lactating mothers; (2) implement community-based water quality monitoring; and (3) transition from open dumping to a sanitary landfill system with proper leachate containment to prevent ongoing groundwater contamination. Protecting vulnerable populations must remain a public health priority until comprehensive waste management reforms are achieved.

References

Abidin, A.U., Maziya, F.B., Susetyo, S.H., Yoneda, M., & Matsui, Y., 2023. Exposure Particulate Matter (PM 2.5) and Health Risk Assessment on Informal Workers in Landfill Site. *Indonesia. Environmental Challenges*, 13(October), pp.100795.

Abidin, A.U., Maziya, F.B., Susetyo, S.H., Yoneda, M., & Matsui, Y., 2024. Heavy Metal Air Pollution in An Indonesian Landfill Site: Characterization, Sources, and Health Risk Assessment for Informal Workers. *Environmental Advances*, 15(February), pp.100512.

Armocida, B., Monasta, L., Sawyer, S., Bustreo, F., Segafredo, G., Castelpietra, G., Ronfani, L., Pasovic, M., Hay, S., Hay, S.I., Abila, D.B., Abolhassani, H., Accrombessi, M.M.K., Adekanmbi, V., Ahmadi, K., Al Hamad, H., Aldeyab, M.A., Al-Jumaily, A., Ancuceanu, R., & Beran, D., 2022. Burden of Non-Communicable Diseases Among Adolescents Aged 10–24 Years in the EU, 1990–2019: A Systematic Analysis of the Global Burden of Diseases Study 2019. *The Lancet Child and Adolescent Health*, 6(6), pp.367–383.

Aprilyani., Amri, A.J.A., Mallongi, A., Ibrahim, E., & Kasim, S., 2025. Environmental Health Risk Analysis of Exposure to Iron (Fe) and Manganese (Mn) in Dug Well Water in Banta-Bantaeng Sub-district, Makassar City. *Journal of Neonatal Surgery*, 14(32S), pp.3371–3383.

Choi, H., Park, M.E., & Bae, J.-H., 2025. Distinct Regional and Seasonal Patterns of Atmospheric NH3 Observed from Satellite over East Asia. *Remote Sensing*, 17(15), pp.2587.

Ding, T.T., Du, S.H., Huang, Z.Y., Wang, Z.J., Zhang, J., Zang, Y.H., Liu, S.S., He, L.S., 2021. Water Quality Criteria and Ecological Risk Assessment For Ammonia in the Shaying River Basin, China, Ecotoxicology and Environmental Safety, 215.

Faraday, E.T., Rotimi, O.M., Ifeanyi, U.J., Moyinoluwa, A., 2024. Risk Assessment and Seasonal Variation of Atmospheric Ammonia in Ondo State, Nigeria. *Discov Atmos*, 2(17).

Gumede, P.R., & Gumede D., 2025. Air Quality and Health Risks of Residents Living Near A Landfill Site in Durban, South Africa. *J Public Health Afr.*,16(1), pp.1274.

Gunarathne, V., Phillips, A.J., Zanoletti, A., Upamali, A., Vithanage, M., Di, F., & Pivato, A., 2024. Science of the Total Environment Environmental Pitfalls and Associated Human Health Risks and Ecological Impacts from Landfill Leachate Contaminants: Current Evidence, Recommended Interventions and Future Directions. *Science of the Total Environment*, 912(August 2023), pp.169026.

Keithley, A.E., Muhlen, C., Wahman, D.G., Lytle, D.A., 2021. Fate of Ammonia and Implications for Distribution System Water Quality at Four Ion Exchange Softening Plants With Elevated Source Water Ammonia. *Water*

Research, 203.

Li, P., & Srinivasamoorthy, D.K.T.S.K., 2021. Sources and Consequences of Groundwater Contamination. *Archives of Environmental Contamination and Toxicology*, 80(1), pp.1–10.

Lin, L., Yang, H., & Xu, X., 2022 Effects of Water Pollution on Human Health and Disease Heterogeneity: A Review. *Front. Environ. Sci.*, 10, pp.880246.

Lukiyono, Y.T., Wikurendra, E.A., & Zain, S.S., 2023. Environmental Health Risk Analysis of Hydrogen Sulfide (H_2 S) and ammonia (NH 3) from Vehicle Fumes Around Purabaya Terminal with a radius of 250 and 500 meters in 2022. *Bali Medical Journal*, 12(3), pp.3319–3321.

Maliga, I., Purwono, S., Harini, R., Hasifah, H., & Lestari, A., 2025. Environmental Health Impacts and Risks of Domestic Wastewater Issues in Small Island. *Jurnal Kesehatan Masyarakat*, 20(4), pp.759–767.

Okyere, E., Bentil, E., Addai, N.A.K., Mensah, L., 2025. Human Health Risk From Groundwater Consumption: A Case Study in the Apaaso-Tafo Community in the Bono East Region of Ghana. *Heliyon*, Vol 11(3).

Mihai, F.C., Gündogdu, S., Markley, L.A., Olivelli, A., Khan, F.R., Gwinnett, C., Gutberlet, J., Reyna-Bensusan, N., Llanquileo-Melgarejo, P., Meidiana, C., Elagroudy, S., Ishchenko, V., Penney, S., Lenkiewicz, Z., & Molinos-Senante, M., 2022. Plastic Pollution, Waste Management Issues, and Circular Economy Opportunities in Rural Communities. *Sustainability (Switzerland)*, 14(1).

Nong, X., Tang, R., Chen, L., & Wei, J., 2024. Environmental Implication Identification on Water Quality Variation and Human Health Risk Assessment In The Middle And Lower Reaches of the Hanjiang River, China. *Human and Ecological Risk Assessment: An International Journal*, 30(5–6), pp.506–528.

Nursanti, I., Murti, B., & Mulyani, S., 2025. The Social Cognitive Theory Model in Predicting Maternal Behavior for Healthy Child Development in Yogyakarta Indonesia. *Jurnal Kesehatan Masyarakat*, 20(3), pp.569–577.

Rivai, A., Rasman, R., Sahani, W., Inayah, I., Ahmad, H., & Suryadi, I., 2024. Risk Assessment Of Ambient Air Pollution PM2.5 Exposure To Communities In The Cement Industrial Area, Pangkep Regency, Indonesia. Malaysian Journal of Medicine and Health Sciences, 20(2), 210–217.

Sakunkoo, P., Thonglua, T., Sangkham, S., Jirapornkul, C., Limmongkon, Y., Daduang, S., Tessiri, T., Rayubkul, J., Thongtip, S., Maneenin, N., & Pimonsree, S. (2022). Human health risk assessment of PM2.5-bound heavy metal of anthropogenic sources in the Khon Kaen Province of Northeast Thailand. *Heliyon*, 8(6), pp.e09572.

Sarles, M., Daud, A., Mallongi, A., Birawida, A.B., Wahyu, A., & Gafur, A., 2024. Environmental Health Risk Analysis of Heavy Metals Copper (Cu) and Arsenic (As) in the Gold Mining Area of PT . Citra Palu Mineral , Central Sulawesi Province. *Pak. j. life soc. Sci.*, 22, pp.23490–23502.

Shetty, S.S., Deepthi, D., Harshitha, S., Sonkusare, S., Naik, P.B., N, S.K., & Madhyastha, H., 2023. Environmental Pollutants and Their Effects On Human Health. Heliyon, 9(9), pp.e19496.

Siddiqua, A., Hahladakis, J.N., Ahmed, W., & Attiya, K.A.Al., 2022. An Overview of The Environmental Pollution And Health Effects Associated With Waste Landfilling And Open Dumping. *Environ Sci Pollut Res*, 58514–58536.

Suaebu, S., Daud, A., Mallongi, A., Wahyu, A., & Amiruddin, R., Health Risks Due to Exposure Nitrate (NO 3) and Ammonia (NH 3) in Local Communities Final Disposal of Waste in Makassar City. *International Journal of Environmental Impacts*, 8(4), pp.825–835.

Suryadi, I., Juherah, J., Rachmawati,S., Fitriani, N., Kahfi, M., & Basri., S., 2025. Exposure of Volunteer Traffic Assistants to PM2.5 From Transportation in Indonesia: An Environmental Health Risk Analysis. *J Prev Med Public Health*. 58(4), pp.379-387.

Suryadi, I., Nugraha, A.P., Fitriani, N., & Rachmawati, S., 2021. The Determinant of Lung Function Disorders of The Textile Industry Spinning Section. *Jurnal Kesehatan Masyarakat*, 17(4), 475–482.

Trach, Y., Trach, R., Kuznietsov, P., Pryshchepa, A., Biedunkova, O., Kiersnowska, A., & Statnyk, I., 2024. Predicting the Influence of Ammonium Toxicity Levels in Water Using Fuzzy Logic and ANN Models. *Sustainability*, 16(14), pp.5835. https://doi.org/10.3390/su16145835

Vaverková, M.D., Adamcová, D., Zloch, J., Radziemska, M., Berg, A.B., Voběrková, S., & Maxianová, A., 2018. Impact of Municipal Solid Waste Landfill on Environment – A Case Study. Journal of Ecological Enggineering. 19(4), pp.55–68.

Yu, G., Wang, J., Liu, L., Li, Y., Zhang, Y., & Wang, S., 2020. The analysis of groundwater nitrate pollution and health risk assessment in rural areas of Yantai, China. *BMC Public Health*, 20(1), pp.1–6.