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Health Risks Due to Exposure Nitrate (NO_3) and Ammonia (NH_3) in Local Communities Final Disposal of Waste in Makassar City

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ABSTRACT

This study aims to evaluate the health risks associated with exposure to nitrate and ammonia among communities living near the Tamangapa Final Disposal Site in Makassar City. The primary objective is to assess the health impacts of contaminated well water used as a drinking water source. The research method used a cross-sectional study with an environmental health risk analysis approach, involving measurements of nitrate and ammonia concentrations in well water and interviews with 76 respondents. Sampling was conducted using purposive sampling, targeting residents near the TPA who rely on well water for daily needs. The results reveal that 27 out of 38 well water samples exceeded safe nitrate limits, while 20 samples exceeded safe ammonia limits. Target Hazard Quotient analysis indicates significant health risks, particularly among adults (THQ > 1). Long-term projections suggest escalating health risks. High exposure frequency exacerbates these health impacts. In conclusion, nitrate and ammonia exposure through well water poses serious health threats, especially to children and adults. Risk management strategies such as water quality monitoring, public education, and advanced water treatment technologies are urgently needed. The study underscores the importance of stricter waste management policies and interventions to safeguard community health near landfill sites.

1. INTRODUCTION

The health risks associated with exposure to nitrate (NO_3) and ammonia (NH_3) in communities surrounding landfill areas are significant and multifaceted. Nitrate contamination primarily originates from the decomposition of organic materials and waste, leading to elevated levels in both groundwater and surface water. This contamination poses a serious threat to public health, particularly through contaminated drinking water sources, direct contact with soil, and inhalation of polluted air. The presence of nitrate in drinking water has been linked to various adverse health effects, including methemoglobinemia (commonly known as "blue baby syndrome"), which primarily affects infants and can lead to severe health complications [1]. Furthermore, research indicates a correlation between nitrate exposure and increased risks of certain cancers, particularly stomach and bladder cancers, especially among populations consuming water with nitrate concentrations exceeding established safety thresholds [2, 3].

Ammonia, a byproduct of waste decomposition, also presents substantial health risks. Exposure to ammonia can cause respiratory tract irritation, eye irritation, and exacerbation of chronic respiratory conditions such as bronchitis. Additionally, ammonia exposure has been associated with neurological effects, particularly in vulnerable populations, including children and the elderly, who demonstrate heightened sensitivity to environmental pollutants [4]. The combined presence of nitrate and ammonia in landfill areas creates a toxic environment that significantly impacts the health of nearby communities.

The vulnerability of landfill-adjacent communities is further compounded by socioeconomic factors and demographic characteristics. Children, the elderly, and immunocompromised individuals face particularly high risks due to their physiological and developmental sensitivities [4-6]. For instance, children exhibit greater gastrointestinal absorption rates for certain substances, making them more susceptible to the harmful effects of nitrate [4]. Moreover, low-income communities often have limited access to clean drinking water and healthcare resources, thereby exacerbating health risks associated with nitrate and ammonia exposure [6].

Groundwater contamination from nitrate and ammonia represents an urgent public health concern, as many communities rely on groundwater as their primary drinking water source. Nitrate infiltration into groundwater occurs rapidly, particularly in agricultural areas where fertilizer use is prevalent, frequently resulting in concentrations that exceed the Maximum Contaminant Level (MCL) established by environmental health standards (10 mg/l) [7].

Maintaining compliance with established concentration thresholds for nitrate and ammonia is crucial for protecting community health. Regular water quality monitoring, combined with effective waste management practices, can substantially reduce risks posed by these contaminants. Given the substantial evidence linking nitrate and ammonia exposure to serious health outcomes, policymakers must prioritize comprehensive risk management strategies. These should include stricter regulations regarding waste disposal and agricultural practices that contribute to nitrate and ammonia pollution, as well as investments in water treatment technologies capable of effectively removing these contaminants from drinking water supplies [3, 5]. Additionally, addressing socioeconomic disparities in pollutant exposure is essential for achieving environmental justice and ensuring universal access to safe drinking water [6].

This study underscores the urgent need for context-specific interventions by revealing alarming contamination levels in Makassar's landfill-adjacent communities. This study underscores the urgent need for context-appropriate interventions by revealing alarming contamination levels in communities adjacent to the landfill in Makassar. Preliminary measurements of well water samples exceed the WHO nitrate threshold, exacerbated by unique local factors such as porous hydrogeology, intensive agricultural practices, and groundwater use near the waste disposal site. Our innovative methodology prioritizes probabilistic risk modeling and long-term exposure projections (5-30 years), providing in-depth insights into cumulative health risks, particularly for vulnerable groups. The methodological novelty and locally grounded evidence presented here not only advance environmental health risk analysis in rapidly developing urban contexts but also create an imperative for policymakers to implement targeted monitoring systems, community-tailored treatment solutions, and zoning regulations that address this invisible public health crisis before irreversible damage occurs.

The theoretical framework for environmental health risk analysis in this study is based on the U.S. Environmental Protection Agency (EPA) risk assessment paradigm, which consists of four key stages: hazard identification, dose-response assessment, exposure assessment, and risk characterization. Hazard identification determines the presence and potential toxicity of environmental contaminants. Dose-response assessment quantifies the relationship between contaminant exposure levels and adverse health effects. Exposure assessment evaluates the magnitude, frequency, and duration of human exposure to contaminants through various pathways (ingestion, inhalation, dermal contact). Finally, risk characterization integrates data from the previous stages to estimate the probability and severity of health risks, particularly for vulnerable populations. This structured approach ensures a scientifically rigorous evaluation of environmental hazards, guiding risk management decisions and policy interventions to protect public health.

2. METHODS

2.1 Types and design of research

This analytic observational research of cross-sectional study design through a health risk assessment approach. A cross-sectional design is a research method that collects data from a population at a single point in time to measure the prevalence of a phenomenon and analyze relationships at that time. Health risk analysis is used to estimate human health risks, both carcinogenic and non-carcinogenic [8].

2.2 Population and sample

This study employed a cross-sectional design with purposive sampling to select 38 dug well water sampling points from 42 households in RW 4 Tamangapa, Makassar, meeting the inclusion criteria: (1) located near Tamangapa Landfill, (2) using well water as daily drinking source, (3) having both adult (> 25 years) and child (6-12 years) respondents willing to participate. Sample size calculation followed Lemeshow's formula (1990) with 95% confidence level and 5% precision, yielding a minimum of 38 households. To compare health risks between adult and child groups, each household contributed one adult and one child respondent, resulting in 76 total respondents. Sampling points were systematically selected considering distance from the landfill (Figure 1), while respondents were proportionally chosen by age group for Environmental Health Risk Assessment (EHRA), integrating nitrate/ammonia concentration data, anthropometric characteristics, and exposure patterns through structured interviews. Research the location area as shown in Figure 1.

2.3 Research instrument

This study employs a rigorous mixed-methods approach, integrating environmental sampling and health surveys. A total of 38 georeferenced groundwater well samples were collected from households located within 0.5–3 km of the Tamangapa landfill during the dry season (July–September 2023) and analyzed for nitrate/ammonia concentrations using standard spectrophotometric methods [9]. The sample size of 38 households was determined using Lemeshow's formula (95% confidence interval, 5% margin of error) from 42 eligible households that met the inclusion criteria (permanent residents using well water with at least one adult (> 25 years) and one child (6–12 years) willing to participate). Data collection included structured questionnaires (water consumption patterns, exposure history, anthropometry) and standardized protocols, with morning sampling (06:00–08:00) to capture peak usage periods. This approach enables a comprehensive exposure assessment for subsequent health risk calculations while ensuring scientific validity through systematic implementation across all study components.

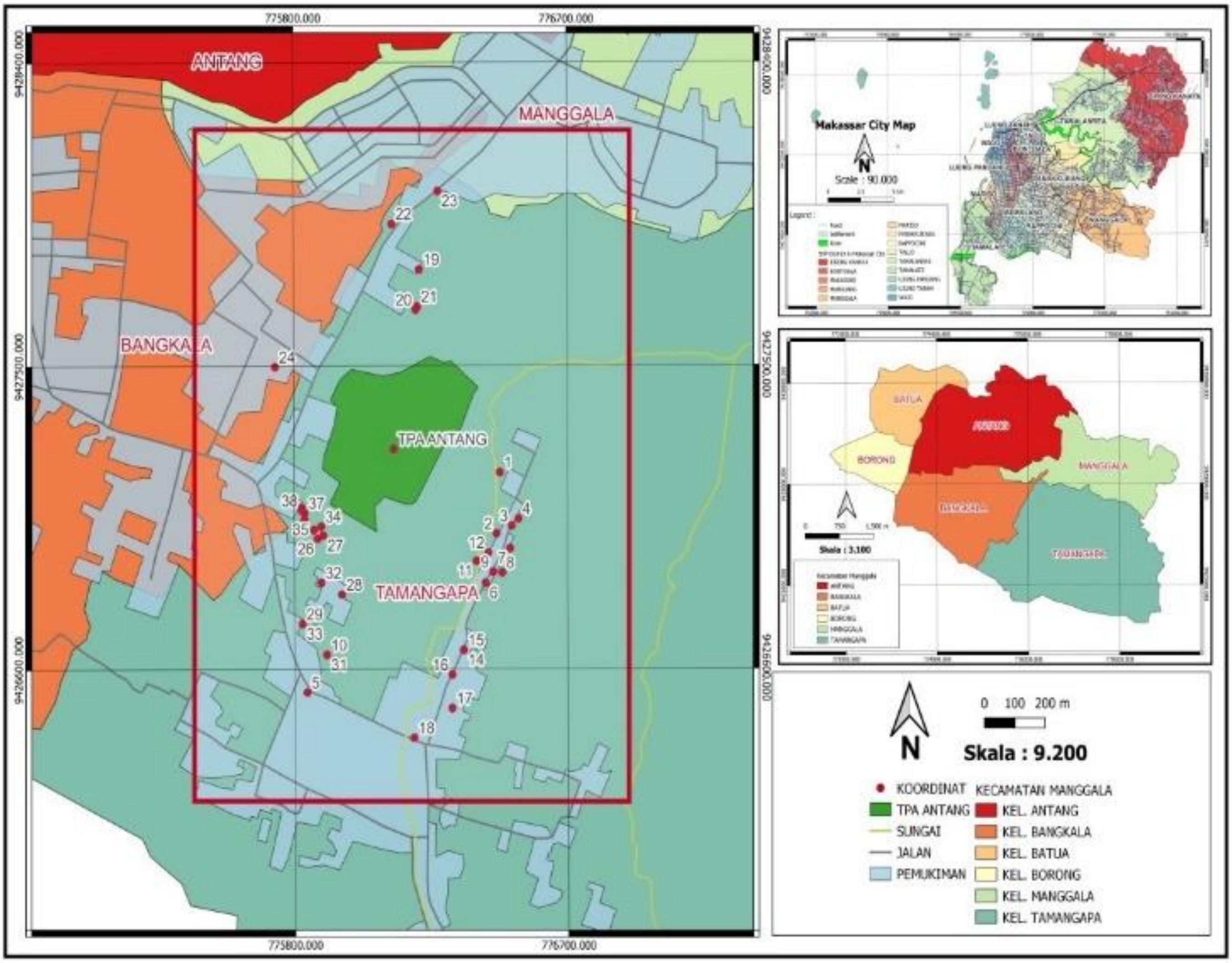

Figure 1. Sampling location points

2.4 Health risk assessment and evaluation

The Environmental Health Risk Assessment was conducted following U.S. EPA guidelines to evaluate community exposure risks from nitrate and ammonia in well water. The values obtained are derived from the concentration of nitrate and ammonia in the media, where the values will be compared with national and international value limits. In the analysis of health risks to nitrate exposure, the risk is determined from intake, duration of exposure, and concentration.

Analysis of dose response is a process of determining material chemical influences to health. Step in analysis dose response aiming for [10]. Descriptions of reference dose (RfD), concentration reference (RfC), and slope factor (SF) are as follows [11]:

RfD and RfC are made into reference for safe value on effects non-carcinogenic an agent risk, while SF is made reference for safe value on effects carcinogenic. RfD for Nitrate and Ammonia parameters as follows:

Table 1. RfD nitrate and ammonia

Parameter	Exposure Path	RfD (mg/kg/day)
Nitrate	Ingestion	1.6 mg/kg/day
	Dermal	1.4 mg/kg/day
Ammonia	Ingestion	3,635 mg/kg/day
	Dermal	0.974 mg/kg/day

Table 1 presents the RfD values for nitrate and ammonia, which indicate the maximum daily exposure that is considered safe for humans. For nitrate, the RfD values are 1.6 mg/kg/day for ingestion and 1.4 mg/kg/day for dermal exposure. In the case of ammonia, the RfD for ingestion is significantly higher at 3.635 mg/kg/day, while the dermal exposure RfD is 0.974 mg/kg/day. These values help assess the potential risks of long-term exposure to these substances through different routes of exposure.

Determination analysis exposure assessment is carried out with method enter values characteristics anthropometry and activity man to in a formula [12]. Risk level it is said safe if RQ < 1. Risk level it is said No safe if RQ ≥ 1. This is means the bigger exposure to risk agents results in the bigger cause risk health so that need done control risk to effect exposure the. Methods for Target Hazard Quotient (THQ) estimation occurs when somebody consume or inhale contaminated substances in a material food or contaminants toxic certain non - carcinogenic and carcinogenic substances.

$$THQ = \frac{EF \times ED \times FIR \times C}{RfD \times Bw \times AT} \times 10^{-3} \quad (1)$$

Information:
EF: Frequency of exposure (365 days/year)
ED: Duration of Exposure (70 Years)

FIR: Intake rate (grams/ Individual /day)
C: Metal concentration
RfD: Reference dose
Bw: Body Weight (Kg)
AT: Average exposure time for non-carcinogenic (365 days/year × ED)

The THQ was selected as the primary risk metric in this study due to its scientific validity and regulatory alignment for assessing non-carcinogenic risks from nitrate and ammonia exposure. THQ is specifically designed for chronic exposure assessment of threshold toxicants, comparing estimated intake (via ingestion/dermal routes) with established reference doses (RfDs). This approach provides conservative, health-protective estimates through its clear risk threshold (HQ ≥ 1 indicating potential adverse effects), while accommodating population-specific variables (e.g., children's higher nitrate absorption rates) and long-term exposure projections (5-30 years). The methodology's reliability is evidenced by its adoption in WHO drinking water quality assessments and peer-reviewed studies on landfill-adjacent communities.

3. RESULTS

According to the test results of nitrate concentrations in clean water sources used by communities that meet the standards in Figure 2, nitrate levels in 11 samples out of 38 samples exceeded the standards, while nitrate levels in 27 well water samples exceeded the standards, in compliance with the Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023 on Environmental Health.

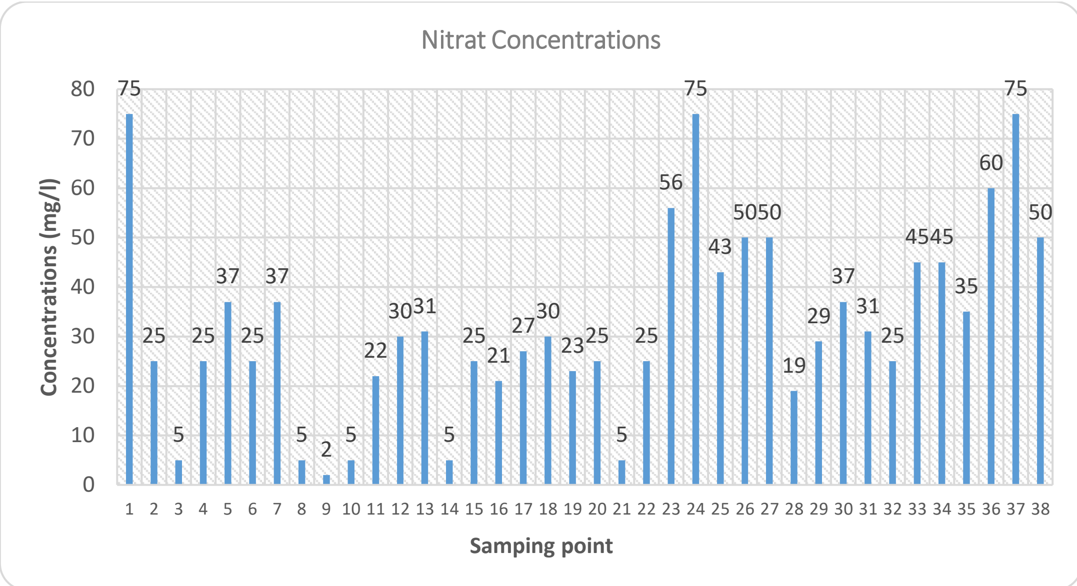

Figure 2. Examination concentration nitrate in clean water sources of communities in around the Tamangapa landfill area

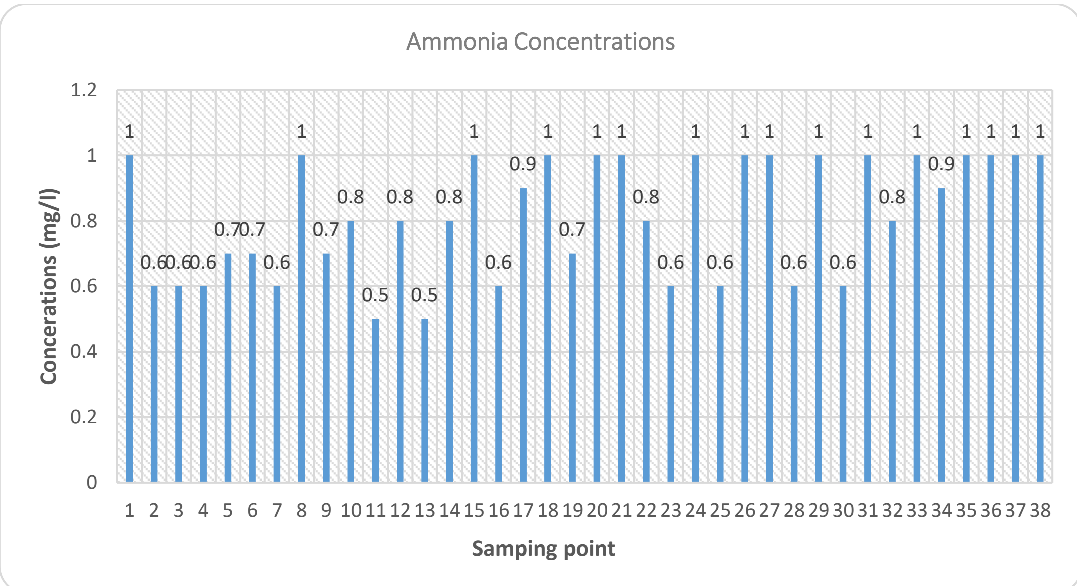

Figure 3. Examination concentration ammonia in clean water sources of the community around the Tamangapa landfill area

Based on the test results of ammonia gas extracted from the wells in Figure 3, the concentrations of 20 samples did not meet the quality standards stipulated in Regulation No. 2 of 2023 of the Minister of Health of the Republic of Indonesia on Environmental Health.

Table 2 shows that Respondent 's weight ranges from 3 – 85 kg and an average of 39.6 kg. The rate of ingestion respondent for children is 1 L/Day and for adults is 2 L/Day. The duration of exposure of respondents ranged from 12 – 67 years with an average of 38 years. The frequency of exposure of respondents ranged from 356 days/year and an average of 356 days/year.

Based on Table 3 it can be known the target value of the real-time non-carcinogenic hazard quotient (TRQ) for Ammonia for 76 respondents (children and adults) was mean adult value 151.7 more tall compared to children that is 86.94 which means the average community around the Tamangapa TPA area at risk experience disturbance health in children and also mature Because THQ value >1. While the THQ lifetime projection year 5th - 30th years for children around 43.7 – 259.2 and adults around 756.2 – 4541.2 so can concluded that lifetime 5 – 30 years community around the Tamangapa TPA area at risk experience disturbance health.

Table 2. Respondent characteristics based on body weight and community activity patterns around the Tamangapa TPA area

Indicator	Min	Max	Mean	Unit
Weight	3	85	39.6053	Kg
Intake Rate (IR)	1	2	1.5000	L/Day
Exposure Duration (ED)	12	67	38.3947	Year
Average Time (AT)	2190	10950	6570	Day
Exposure Frequency (EF)	356	356	356	Day/ Year

Source: Primary data 2024

Table 3. Min, max, and mean THQ values of ammonia ingestion pathway around the Tamangapa TPA area

THQ (ml/L / day)	Min		Max		Mean		Information	
	Children	Mature	Children	Mature	Children	Mature	Children	Mature
Realtime	13.44	73.88	210.5	511	86.94	151.7	At risk	At risk
Lifetime	**Children**	**Mature**	**Children**	**Mature**	**Children**	**Mature**		
Year 5	66.2	36.1	105.2	255.7	43.7	756.2		
10th Year	133.4	73.3	210.5	511.4	86.4	1513.2		
15th Year	199.6	110.1	315.7	767.1	129.1	2270.5		
20th Year	266.8	147.4	421.0	1022.8	172.8	3027.7		
25th Year	333.1	184.6	526.2	1278.6	216.5	3784.9		
30th Year	399.2	221.7	631.5	1534.3	259.2	4541.2		

Description: MS (Meets requirements) Terms), TMS (Does Not Meet) Condition), CD (Children), MT (Mature)
* Notes: At risk if THQ > 1, no at risk if THQ < 1
Source: Primary data 2024

Table 4. Min, max, and mean THQ values of dermal path ammonia around the Tamangapa landfill area

THQ (mgl /L / day)	Min		Max		Mean		Information	
	Children	Mature	Children	Mature	Children	Mature	Children	Mature
Realtime	0.2807	131.86	0.9356	316.5	0.4973	21.23	No Risk	At risk
Lifetime	**Children**	**Mature**	**Children**	**Mature**	**Children**	**Mature**	**Children**	**Mature**
Year 5	1.4034	657.30	4.6778	158.7	2.4866	107.1	At risk	At risk
10th Year	2.8067	131.6	9.355	316.4	4.9732	215.3		
15th Year	4.2101	197.9	14.03	474.2	7.4599	323.5		
20th Year	5.6134	263.2	18.71	632.9	9.9465	430.6		
25th Year	7.0168	328.5	23.38	790.7	12.43	538.8		
30th Year	8.4201	394.8	28.06	949.4	14.91	646.0		

Description: MS (Meets requirements) Terms), TMS (Does Not Meet) Condition), CD (Children), MT (Mature)
* Notes: At risk if THQ > 1, no at risk if THQ < 1
Source: Primary data 2024

Based on Table 4, it can be known the target value of the real-time non- carcinogenic hazard quotient (TRQ) for Ammonia for 76 respondents (children and adults) was mean adult value 215.2 more tall compared to children namely 0.4973 which means the average community around the Tamangapa TPA area no at risk experience disturbance health in children, but for mature at risk experience disturbance health because THQ value > 1. While the THQ lifetime projection year 5th - 30th years for children around 2.4866 – 14.91 and adults around 107.17 – 646.0 so can concluded that lifetime 5 – 30 years community around the Tamangapa TPA area at risk experience disturbance health.

Based on Table 5, it can be known the target value of the non- carcinogenic real-time hazard quotient (TRQ) for nitrate for 76 respondents (children and adults) was mean adult value 606.62 more tall compared to children namely 34.21 which means the average community around the Tamangapa TPA area at risk experience disturbance health in children and also mature at risk experience disturbance health Because THQ value > 1. While the THQ lifetime projection year 5th - 30th years for children around 173.0 – 104.5 and adults around 303.1 – 1818.8 so can concluded that lifetime 5 – 30 years community around the Tamangapa TPA area at risk experience disturbance health.

Based on Table 6 it can be known the target value of the real-time non- carcinogenic hazard quotient (TRQ) for nitrate for 76 respondents (children and adults) was mean adult value 1.048 more tall compared to children namely 0.0280 which means the average community around the Tamangapa TPA area No at-risk experience disturbance health in children However For mature at risk experience disturbance health Because THQ value >1. While the THQ lifetime projection year 5th - 30th years for children around 0.1403 – 0.8420 and adults around 5.2406 – 31.44 so can concluded that lifetime 5 – 30 years community around the Tamangapa TPA area No at-risk experience disturbance health for children However For mature at risk experience disturbance health.

Table 5. Min, max, and mean THQ values of nitrate ingestion pathway around the Tamangapa TPA area

THQ (ml/L / day)	Min		Max		Mean		Information	
	Children	Mature	Children	Mature	Children	Mature	Children	Mature
Realtime	35.83	47.24	131.4	20.34	34.21	60.62		
Lifetime	**Children**	**Mature**	**Children**	**Mature**	**Children**	**Mature**		
Year 5	175.1	238.2	65.125	104.7	173.0	303.1		
10th Year	350.3	476.4	131.2	208.4	347.1	606.2		
15th Year	526.5	714.6	197.3	312.2	521.2	909.4	At risk	At risk
20th Year	701.7	953.8	263.5	416.9	694.3	1212.5		
25th Year	877.9	1191.0	328.6	520.6	868.4	1515.6		
30th Year	1052.1	1142.1	394.7	624.3	1042.5	1818.8		

Description: MS (Meets requirements) Terms), TMS (Does Not Meet) Condition)
* Notes: At risk if THQ > 1, no at risk if THQ < 1
Source: Primary Data 2024

Table 6. Min, max, and mean THQ values of dermal path nitrate around the Tamangapa TPA area

THQ (ml/L / day)	Min		Max		Mean		Information	
	Children	Mature	Children	Mature	Children	Mature	Children	Mature
Realtime	0.0281	1.0354	0.0281	1.0839	0.0280	1.0481	No Risk	At risk
Lifetime	**Children**	**Mature**	**Children**	**Mature**	**Children**	**Mature**	**Children**	**Mature**
Year 5	0.1403	5.1768	0.1403	5.4195	0.1403	5.2406		
10th Year	0.2807	10.35	0.2807	10.83	0.2806	10.48		
15th Year	0.4210	15.53	0.4210	16.25	0.4210	15.72	No Risk	At risk
20th Year	0.5613	20.70	0.5613	21.67	0.5613	20.96		
25th Year	0.7017	25.88	0.7017	27.09	0.7016	26.20		
30th Year	0.8420	31.06	0.8420	32.51	0.8420	31.44		

Description: MS (Meets requirements) Terms), TMS (Does Not Meet) Condition), CD (Children), MT (Mature)
* Notes: At risk if THQ > 1, no at risk if THQ < 1
Source: Primary Data 2024

4. DISCUSSIONS

Higher ingestion rate tall generally owned by adults, while rate more ingestion low possibility reflect children or individual with more activities. Effect drinking water consumption that has level ammonia and nitrate height is very related with level and duration exposure. Generally, the taller level ammonia and nitrate and the longer the exposure, the effect toxic will also bigger. The taller intake exposure the taller risk disturbance health caused [13, 14]. Concentration high ammonia This Possible due to distance the well is near with TPA. Well water polluted by water seepage from results decay rubbish around it [15].

Long-term exposure to environmental contaminants increases health risks, as prolonged consumption of contaminated drinking water raises intake levels and the likelihood of adverse health effects [16]. All respondents live near the Tamangapa landfill and rely on groundwater for daily consumption, leading to continuous exposure to ammonia and nitrate, which may cause health disturbances. Previous studies have shown that higher exposure frequency over a year correlates with increased health risks. The primary entry route of ammonia and nitrate into the human body is through ingestion of contaminated drinking water. Intake calculations are influenced by contaminant concentrations in groundwater, consumption rate, exposure frequency, duration, and body weight. For exposure frequency, the default value of 350 days/year is used, as recommended by the US-EPA (1997) for residential drinking water exposure, while other variables are based on interviews with 76 respondents [17].

4.1 Target Hazard Quotient (THQ) ammonia ingestion pathway

Ammonia exposure through ingestion presents significant public health concerns near the Tamangapa landfill, as demonstrated by THQ analysis. The assessment revealed alarmingly high non-carcinogenic risks, with mean THQ values of 864,230.94 for children and 151,394,085.7 for adults - both substantially exceeding the safety threshold (THQ > 1) [18]. Lifetime projections showed escalating risks, reaching 4,321,154.7 (children) and 756,970,428.2 (adults) after 5 years of exposure, indicating potential for severe neurological, respiratory, and cardiovascular effects [19].

The toxicological profile of ammonia explains these findings: when ingested, it disrupts acid-base balance, potentially causing metabolic alkalosis and impairing hepatic function [20]. Children exhibit particular vulnerability due to immature detoxification systems and higher water intake per body weight, despite lower absolute THQ values compared to adults. Clinical manifestations may include nausea, vomiting, and cyanosis, with severe cases leading to metabolic disturbances and respiratory compromise [21-23].

Nitrate (NO_3) exposure primarily occurs through ingestion and is classified as non-carcinogenic. Potential health effects from consuming nitrate-contaminated water include decreased blood pressure, severe headaches, dizziness, vision disturbances, skin flushing, excessive sweating, cyanosis, nausea, vomiting, fainting, and respiratory distress [23].

Risk evaluation using the THQ indicates the need for preventive measures to reduce ammonia exposure among communities near the Tamangapa landfill. These measures should include improvements in waste management systems to minimize environmental ammonia contamination and enhancements in drinking water treatment to ensure better water quality [24-26]. Stricter regulatory policies are also necessary to control ammonia levels in the environment. Authorities must establish clear concentration limits for ammonia in water and enforce rigorous monitoring to prevent exceedances. The high THQ values observed in this study indicate a significant non-carcinogenic health risk, highlighting the urgency of immediate intervention [27].

4.2 THQ of dermal pathway ammonia

Dermal exposure to dissolved ammonia presents significant health risks due to its corrosive properties and high reactivity with skin tissues. Epidemiological evidence demonstrates concentration-dependent dermal damage, ranging from mild irritation to severe chemical burns characterized by blister formation, epidermal necrosis, and coagulative tissue damage [20]. Clinical cases report that prompt irrigation can mitigate injury severity, though occupational exposures often require skin grafting when involving concentrated ammonia solutions or vapors [20]. The dermal THQ analysis revealed substantially elevated risks among adults, attributable to frequent contact with contaminated water during domestic activities (bathing, washing) and occupational exposures [23, 28]. High THQ values in adults show the need quick action to reduce exposure and protect public health.

To mitigate health risks associated with ammonia exposure through dermal pathways, several strategies should be implemented. Public education on ammonia hazards and exposure reduction methods is essential. Additionally, active monitoring, water treatment processes, and stakeholder education on effective drinking water treatment techniques are necessary to ensure safe water use for bathing and washing. Preventive measures must be enforced to minimize long-term health impacts and safeguard public well-being [29].

4.3 THQ nitrate ingestion pathway

The ingestion pathway represents a particularly hazardous exposure route for nitrate contamination due to its complex toxicokinetics and significant health implications. Following consumption, nitrate is rapidly absorbed in the upper gastrointestinal tract, with approximately 6-7% being reduced to nitrite by oral microbiota before entering the stomach, where gastric acid facilitates its conversion to reactive nitrogen species, including nitrous acid (HNO_2), dinitrogen trioxide (N_2O_3), and nitrogen dioxide (NO_2).

These reactive intermediates participate in nitrosation reactions that form carcinogenic N-nitroso compounds (NOCs), with the process being influenced by multiple factors, including pH, presence of catalysts, and competitive inhibitors [3]. Pediatric populations demonstrate particular vulnerability to nitrate toxicity, as evidenced by a Moroccan cross-sectional study showing a 22% increased risk of methemoglobinemia among infants consuming water with nitrate concentrations >50 mg/L (11.3 mg/L as NO_3-N) compared to those exposed to lower levels [30], while adults face cumulative risks from chronic exposure through contaminated drinking water sources. The THQ analysis revealed substantial health risks across all age groups, with children's heightened susceptibility (average HQ = 1.39) attributable to greater gastrointestinal absorption rates, higher water intake per body weight, and immature detoxification systems [30, 31]. This is in line with research conducted before, confirming significant non-carcinogenic risks from groundwater nitrate exposure. Effective risk mitigation requires a multi-tiered approach combining advanced centralized treatment systems (ion exchange, reverse osmosis, and electrodialysis achieving >80% nitrate removal [32, 33]. Point-of-use technologies (distillation and activated carbon filtration), source water protection programs, and targeted community education about alternative water sources, as conventional water treatment processes (coagulation, sedimentation, filtration, and chlorination) prove ineffective against nitrate due to its high solubility and stability in aqueous environments [33]. These interventions are urgently needed given the elevated THQ values and the dual risks of both acute methemoglobinemia (particularly in infants) and potential long-term carcinogenic effects from NOC exposure, underscoring the critical importance of implementing comprehensive nitrate risk management strategies to protect public health [34].

4.4 Dermal pathway nitrate THQ

The dermal exposure pathway to nitrate in the Tamangapa landfill area demonstrates distinct risk patterns between age groups, as evidenced by THQ analysis. Current exposure assessments reveal non-carcinogenic risks for children (mean THQ = 0.028) but significant risks for adults (mean THQ = 1.048), exceeding the safety threshold (THQ > 1). Projected lifetime exposure shows escalating risks, with adult THQ values increasing from 5.241 (5-year) to 31.444 (30-year), while children's exposure remains below risk thresholds (0.140-0.842). This differential vulnerability stems from adults' greater occupational and domestic exposure duration during water-related activities. While dermal absorption of nitrate is less efficient than ingestion, chronic exposure through contaminated water may lead to systemic accumulation [35].

The metabolic conversion of nitrate to nitrite by dermal microbiota and subsequent formation of N-nitroso compounds (NOCs) poses particular concern due to their carcinogenic and mutagenic properties. Although current THQ values suggest limited pediatric risk, the potential for nitrite-induced methemoglobinemia and oxygen transport impairment warrants precautionary measures [36]. These findings underscore the necessity for: (1) regular biomonitoring of high-risk populations, (2) protective equipment for workers, and (3) public education about proper hygiene practices when handling contaminated water [37]. The demonstrated adult risks highlight an urgent need for regulatory interventions to limit dermal nitrate exposure in landfill-adjacent communities [35].

4.5 Health risks

This study reveals significant health risks from exposure to nitrate (NO_3^-) and ammonia (NH_3) in well water near the Tamangapa landfill. THQ analysis showed values exceeding safety thresholds (THQ > 1), particularly in adults with long-term exposure. The 30-year projected THQ values reached 31.44 for nitrate and 4,541.2 for ammonia via ingestion, indicating potential serious health effects, including methemoglobinemia, neurological damage, and increased colorectal cancer risk (HR: 1.08-1.25), while children showed lower THQ values, they remain vulnerable due to physiological factors like faster metabolism and immature detoxification systems [31, 38]. Groundwater, as a primary drinking source, faces increasing anthropogenic threats, particularly near landfills where leachate - a toxic byproduct of waste decomposition containing complex organic/inorganic compounds and pathogenic microorganisms - migrates vertically and horizontally to contaminate aquifers [39, 40].

Field surveys reveal inadequate well construction, including 3.8m diameter concrete wells with cracks and unprotected wells, significantly increasing infiltration risks. Chronic nitrate exposure poses serious age-dependent health effects, with adults showing highest non-carcinogenic risks including: colorectal cancer (HR=1.08-1.25), 49% elevated cancer risk at >10mg/day intake and methemoglobinemia/thyroid dysfunction [41]. while ammonia causes respiratory tract damage and chemical burns. Risk analysis identifies exposure duration and consumption volume as key determinants, with adults' higher water intake increasing Risk Quotient (RQ) values despite children's physiological vulnerability, as corroborated by Zhai China study on demographic susceptibility factors. These findings necessitate urgent implementation of: (1) improved well construction standards using impermeable materials, (2) regular groundwater quality monitoring in risk zones, (3) alternative water provision for landfill-adjacent communities, (4) public health education on safe water practices, and (5) community-based water treatment technologies, requiring integrated technical, educational and policy approaches to protect vulnerable populations while advancing SDG 6 targets in high-risk areas [42].

4.6 Management risk

The management of ammonia and nitrate exposure represents a critical public health priority for communities surrounding the Tamangapa landfill. Our risk assessment calculations have established distinct safe exposure durations for adult and pediatric populations, derived through scientific evaluation of key parameters including body weight, reference doses (RfDs), contaminant concentrations, ingestion rates, and absorption factors [18]. The analysis reveals children's heightened vulnerability to ammonia and nitrate toxicity due to physiological factors, necessitating prioritized protective interventions [43].

Risk control measures should also include improving infrastructure and procedures at landfills to reduce ammonia and nitrate pollution. This could include better waste management, the use of advanced technology to handle hazardous contaminants, and strict monitoring of waste management practices. Cooperation between the government, landfill managers and the community is essential to ensure that these measures are implemented effectively and sustainably [22].

4.7 Subtraction exposure through education and community

Effective risk management of ammonia and nitrate exposure requires a multifaceted approach combining public education, technological innovation, and community engagement. Public education programs should focus on raising awareness about health risks while promoting protective measures, including proper hygiene practices and identification of safer water sources [44]. Community based water quality monitoring initiatives have been shown to empower residents while improving surveillance capabilities, as demonstrated in similar landfill-adjacent communities [45].

Emerging hybrid systems combining biological and physiochemical processes show promise, with recent trials achieving 92% ammonia removal through integrated aerobic-anaerobic reactors [22]. For water treatment, centralized systems should incorporate advanced methods such as biofiltration and reverse osmosis, which can remove 80-95% of nitrate contaminants according to EPA guidelines. At the household level, point-of-use reverse osmosis devices have proven particularly effective, with studies showing 85-90% nitrate removal efficiency in field applications [46]. Implementation success depends on institutional collaboration and adaptive management. The WHO recommends phased deployment approaches tailored to local conditions, emphasizing the importance of maintenance training and continuous monitoring [47, 48]. This comprehensive strategy aligns with SDG 6 targets while addressing both immediate health risks and long-term water security in affected communities.

4.8 Supervision and monitoring sustainable

Supervision and monitoring Water quality around the landfill is very important for ensure that concentration ammonia and nitrate still is at within safe limits. This can be done by involving local communities in environmental monitoring programs and providing training on simple ways to reduce exposure [47]. The use of advanced sensors and real-time monitoring technology can provide accurate and up-to-date data on ammonia and nitrate concentrations, which can be used to take immediate action if significant increases occur.

Collaboration between the government, landfill managers, and the community is essential to strengthen involvement in groundwater resource management as a foundation for achieving sustainable water services and ensuring that these measures are implemented effectively. With a comprehensive and collaborative approach, it is hoped that environmental conditions around the Tamangapa landfill can continue to improve, so that the risk of exposure to ammonia and nitrate can be controlled more effectively [48, 49].

5. CONCLUSIONS

This study demonstrates that groundwater contamination from nitrate and ammonia near the Tamangapa landfill poses severe health risks to surrounding communities, with Target Hazard Quotient (THQ) values significantly exceeding safe thresholds for both adults and children. Chronic exposure to these contaminants through drinking water was associated with serious health effects including methemoglobinemia, neurological impairments, and elevated cancer risks, particularly affecting vulnerable groups such as children and immunocompromised individuals due to their physiological susceptibility. The findings emphasize the critical need for immediate intervention through integrated water treatment solutions like reverse osmosis and biofiltration, combined with community education programs to promote safer water practices and enhanced monitoring systems. Furthermore, the implementation of stricter landfill management policies is essential to prevent further groundwater pollution and protect public health. These measures not only address current health risks but also contribute to achieving Sustainable Development Goal 6 (clean water and sanitation) in affected regions. Future research should prioritize longitudinal studies to assess intervention effectiveness and explore innovative, cost-efficient remediation technologies for similar contamination scenarios in developing urban areas.

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