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Original Research Article

Environmental Health Risk Assessment of Lead (Pb) Exposure in Well Water Near to a Cement Industry

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ABSTRACT

The cement industry is one of the sources of heavy metal pollution that has the potential to negatively impact the environment, either through air, soil, or water. The objective of the current study is to determine the health risks of the population living near the cement industry and to develop measures to manage these risks. This is planned to be achieved by investigating the levels of concentration of Pb in well water, the rate of their entry, and the duration and frequency of exposure in the population. This study used a purposive sampling method, and the number of samples was calculated using the Slovin formula, which resulted in 20 well water sampling points and 40 human samples. This study analysed intake, risk quotient (RQ), and risk management. The novelty of this study lies in the fact that individuals residing near the cement industry face health risks not only from air exposure, but also from the consumption of well water. This is based on the calculation results, which show that heavy metal Pb in well water samples around the cement industry can pose a risk to the community both in real time and lifetime. The RQ value of Pb in adult respondents ranged from 0.224 to 1.349 and 0.289 to 1.734 for children. This study could influence the cement industry to focus more on waste disposal and manage their environmental effects on water. Regular checks and the use of exhaust emission filters, along with well covers, can significantly reduce the industry's environmental impact.

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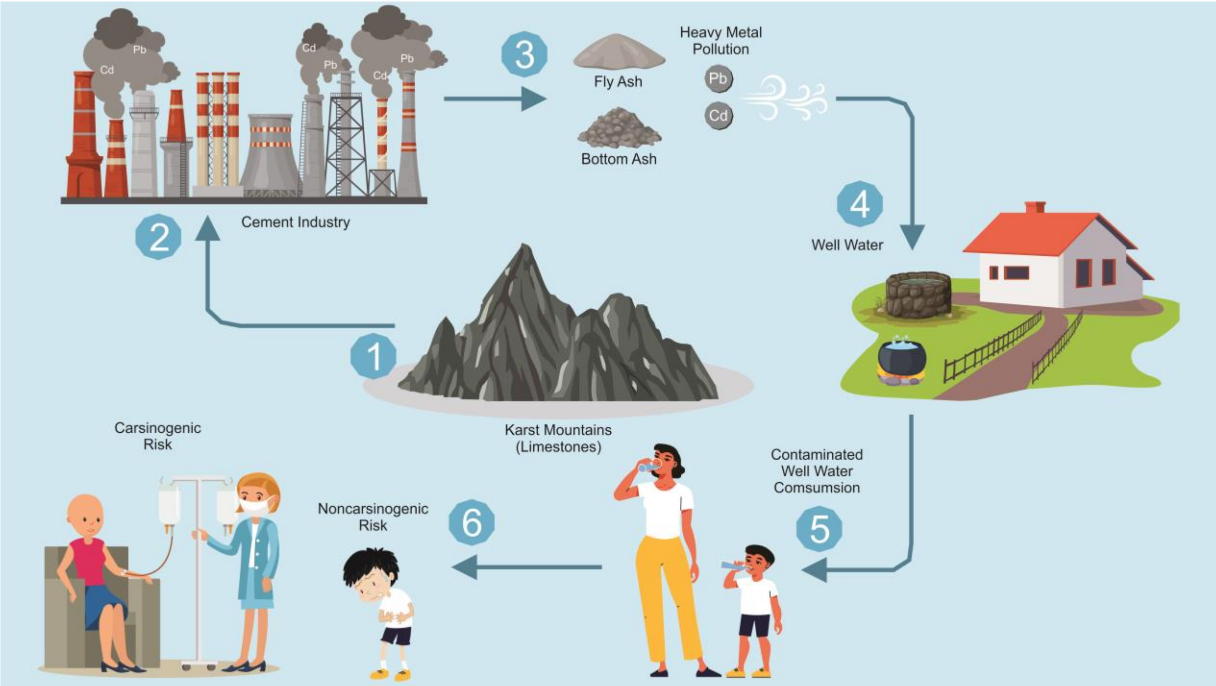
GRAPHICALABSTRACT



Introduction

Cement plants pollute the environment through air and water emissions from the production process and the use of coal, which has a negative impact on the environment and surrounding communities [1,2]. Sedimentary rocks, the raw materials for cement, contain harmful metals such as Ca, Cd, As, Hg, Pb, Cr, Cu, Zn, and Ni, which can pollute water, air, and soil, degrade water quality, and interfere with its function [3,4]. Water quality in a region is influenced by natural processes, such as lithology and aquifer interactions, as well as human activities such as agriculture, industry, and urbanization [5,6]. Quality drinking water is essential for public health. Besides being important, water also has the potential to transmit diseases. Raw water sources can come from reservoirs, rainwater, and groundwater [1,7,8]. We must treat industrial wastewater before discharge to ensure it does not contaminate water sources and meets drinking water quality requirements [9,10] Heavy metals contained in industrial exhaust emissions can contaminate water resources and are harmful to health if ingested. These nonessential heavy metals can accumulate in the body and cause health problems [11], some of which can even cause death [12]. Heavy metals from cement industry emissions can contaminate water in several ways. In the cement production process, exhaust gases and dust containing heavy metals such as lead can be released into the air, and then fall to the ground or water when it rains [13]. Poorly managed sewage can also introduce heavy metals into water sources. Heavy metals can accumulate in aquatic organisms, which can have adverse effects on human health and the environment [14-16]. Heavy metals have the potential to cause death and disease through contamination of clean and drinking water. The use of low-quality water has a negative impact on public health [17,18]. Water pollution can be a risk factor for a number of illnesses ranging from common stomach aches, worms, and dysentery to urinary tract infections [19,20]. Toxins in water can contaminate the human food chain and enter the human body, causing diseases such as typhoid, cholera, diarrhoea, and hepatitis [21,22].

In addition, heavy metal contamination can lead to neurological disorders, including brain damage and developmental disorders in children, as well as internal organ diseases such as kidney and liver damage [23,24]. Heavy metals can trigger cancer, immune system disorders, and bleeding and interfere with bone growth, which can lead to bone fragility [25,26].

Based on several studies that have been conducted on water conditions around industrial areas, it can be seen that heavy metals, such as lead, can be contained in several water sources, including well water around industrial areas. Large industries, particularly those located near residential areas without a barrier or green fiber that separates settlements from industrial sites, have the potential to cause pollution [22,27]. One of the large and growing industries in the South Sulawesi region is the PT Semen Tonasa industry located in Bungoro District, Pangkajene, and Islands Regency.

Lead is a nonessential heavy metal that is difficult to decompose and is accumulative, causing toxicity if accumulated in the body. Although used in various industrial products, Pb is a pure toxic material with no function for the organism [28]. Pb is toxic to humans and can enter through several routes. Acute toxicity causes gastrointestinal disorders, while chronic can cause fatigue, infertility, menstrual disorders, depression, and sleep disturbances [29,30].

Pb can contaminate water sources, including well water, near large industries that do not have clear boundaries with residential areas [5]. One of the large and growing industries in the South Sulawesi region is PT Semen Tonasa, which is located in Bungoro District, Pangkajene, and Islands Regency. Biring Ere Village is one of the villages located close to PT Semen Tonasa. Irfandi, Ashar, and Chahaya's (2013) research talks about the amount of lead (Pb) in the water that people who live near the Aki Recycling Industry get from their dug wells. They found that 60% of these wells have a high risk of becoming polluted. All samples contain levels of lead, with 90% of them meeting the requirements based on Minister of Health Regulation Number 416/Menkes/Per/IX/1990. Based on the Minister of Health Regulation Number 492/Menkes/Per/IV/2010, some samples contain unqualified levels of lead (100%). Alisa, Albirqi P., and Faizal (2020) used AAS (Atomic Absorption Spectrophotometry) to find out how much Pb and other heavy metals were present. The results showed that the Pb content in water ranged between 0.5122 and 0.6003 mg/L. These results are considered to exceed the quality standards. The objective of the current study is to determine the health risks of the population living near the cement industry and to develop measures to manage these risks. This is planned to be achieved by investigating the levels of concentration of heavy metal Pb in well water, the rate of their entry, and the duration and frequency of exposure to heavy metals in the population. In contrast, this is the first study to look at the health risks of people living near the cement industry through drinking water. The health risks were calculated by finding out how much heavy metal was in the water using an approach called environmental health risk assessment, which looks at where the contamination comes from and how people are exposed to health risks.

Materials and Methods

This study is a quantitative study whose data collection is carried out directly (field research), which begins with taking well water samples from the community around the cement industry and then testing them in the laboratory with the ICP (*inductively coupled plasma)* method to see how much heavy metal content (Pb) is contained in them.

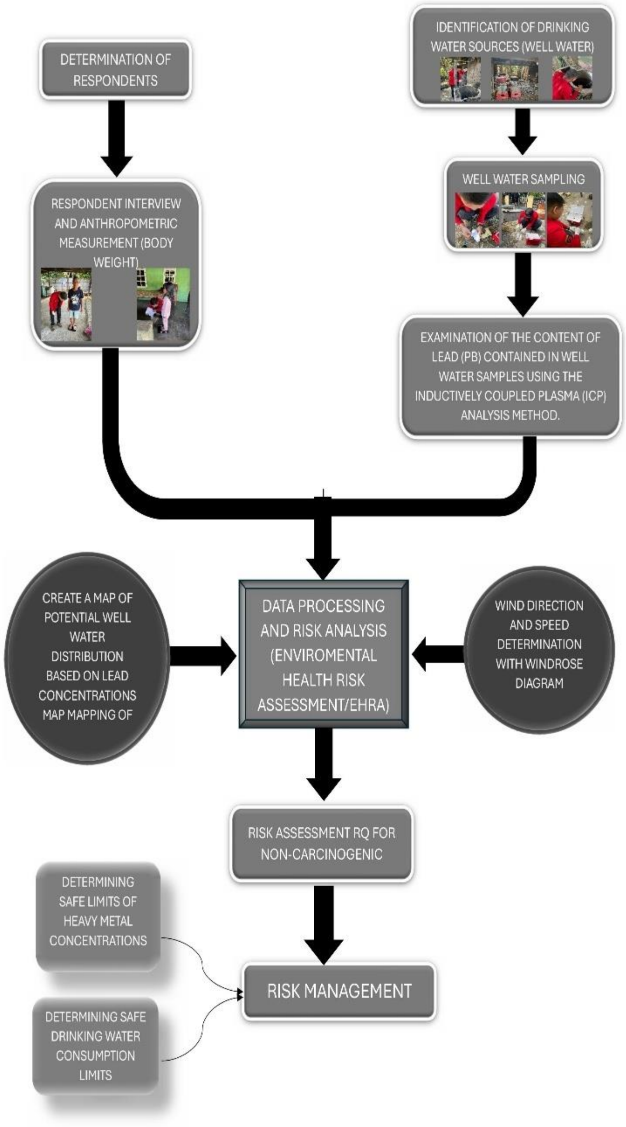


Figure 1. Research flowchart (Source: Primary data, 2024).

In this study, interviews and questionnaires were used to find out things like body weight, age, ingestion rate, exposure frequency, and exposure duration. This information will be used to figure out the community's *chronic daily intake* (CDI) and the level of risk. Exposure that enters the community is not only through the air; this study found that public health risks are also through exposure to drinking water, so risk management is needed not only in the air, but also in drinking water. This is in line with the data on diseases that are often experienced by the community, namely those related to drinking water, such as diarrhoea and skin diseases.

Research design and location

This study is an analytical observational study with an Environmental Health Risk Assessment (EHRA) approach with the aim of assessing the magnitude of human health risks caused by heavy metal exposure. This study also presents wind direction and speed, which can be used as a brief but complete indicator of the distribution of wind speed and direction that is dominant in the spread of pollutants at the study site. Risk characterization is expressed as RQ for non-carcinogenic effects. Non-carcinogenic risk levels are expressed as unitless exponent numbers. The risk level is considered safe if the RQ ≤ 1. The risk level is considered unsafe if the RQ value is > 1 (Ministry of Health, 2012). This work was conducted in April-May 2024 in Biring Ere Village, Bungoro District, Pangkajene Islands Regency, South Sulawesi Province. The choice of location in Biring Ere Village is due to its location, which is very close to the PT Semen Tonasa industry, and its people, who still use well water for their daily needs, so that they have a great potential to be affected by polluted well water. The research location in this study is shown in Figure 2, namely Biring Ere Village, which is in ring 1 of PT Semen Tonasa. This is the village most exposed to pollution caused by industrial processes around the cement factory.

Population and sample

The population in this study included 3,738 residents of Biring Ere Village who were at risk of exposure to lead. The study collected water samples using the integrated sampling technique, which included a total of 20 well water samples, as determined by the Slovin formula. The method of taking water sources is in accordance with the Indonesian national standard (SNI) 6989.58:2008. Human sampling in this study, which meets the sample selection criteria, is using well water for consumption. The number of samples to be taken in this study was calculated based on the number of well samples, namely 2 human samples for each well water sample. Therefore, the study included 40 human samples, with 20 samples for children and 20 samples for adults.

Table 1 presents the concentrations of the heavy metal Pb in the well water of the community of Biring Ere village. Table 1 indicates that the concentrations of Pb in Biring Ere village vary at each well sample point. The highest Pb concentration at point 11 was 0.1289 mg/L. Pb levels have exceeded the maximum threshold allowed in the Regulation of the Minister of Health of the Republic of Indonesia No. 2 Year 2023. In detail, the Pb concentration exceeds the provision of 0.01 mg/L.

Research instruments

Questionnaires and interviews

Based on the US-EPA, in the process of calculating the Environmental health risk assessment, researchers need data such as age, weight, length of exposure, intake rate and frequency of exposure to well water to calculate the amount of health risks that can occur so that interviews are conducted in the community. The instrument used to analyze the content of heavy metal Pb in well water uses the inductively coupled plasma (ICP) method.

Risk assessment and environmental health risk

To figure out the level of public health risk, data processing uses risk assessment calculations, specifically intake.

Table 1. Well water sampling coordinates and heavy metals concentrations

Number	Coordinates		Heavy Metal
	X	Y	Pb
1	119.614570	-4.778901	0.1111
2	119.613104	-4.778187	0.1086
3	119.611486	-4.777987	0.1048
4	119.610325	-4.778082	0.1048
5	119.609183	-4.778710	0.1075
6	119.608992	-4.779872	0.1072
7	119.609021	-4.781861	0.0817
8	119.608222	-4.783003	0.1051
9	119.607888	-4.784478	0.1199
10	119.606147	-4.784916	0.0935
11	119.606927	-4.786544	0.1289
12	119.605290	-4.788942	0.1176
13	119.604262	-4.790712	0.0954
14	119.603607	-4.792721	0.1253
15	119.609696	-4.786268	0.1016
16	119.611680	-4.785996	0.0893
17	119.612694	-4.784212	0.1144
18	119.610638	-4.782698	0.0939
19	119.613350	-4.782035	0.0929
20	119.611980	-4.781007	0.1039

The intake calculation was based on information about the amount of lead in drinking water (mg/L), the rate at which it was consumed (L/h), the number of days per year that it was exposed, the length of time it was exposed (in real time and lifetime years), the person's weight (kg), and the average amount of time (30 years x 365 days per year for non-carcinogenic effects).

$$CDI\ Oral = \frac{CW\ x\ IR\ x\ EF\ x\ ED}{BW\ x\ AT} \quad (1)$$

Where,
CW= Contaminant concentration in water (mg/liter)
IR= ingestion rate (Litres of water/day)
EF= exposure frequency (days/year)
ED= exposure duration (year)
BW= body weight (kg)
AT= average time *(for carci AT=ED x 365 days)*

$$RQ = \frac{CDI}{RfD} \quad (2)$$

Where,
RQ= Risk Quotient
CDI= Chronic Daily Intake
RfD= Reference Dose

Once the environmental health risk assessment is completed and a risk quotient (RQ) value > 1 is obtained, a risk management strategy should be implemented. This involves determining safe intake limits and amounts [9].

Results and Discussion

Biring Ere Village is located in Bungoro District, Pangkajene Kepulauan Regency, South Sulawesi Province, Indonesia. Biring Ere village is included in Ring 1 of the PT Semen Tonasa industrial area, even the location of residents' houses in Biring Ere Village is only a few hundred meters from the PT Semen Tonasa factory. Figure 2 shows that the research location is directly opposite the cement industry.

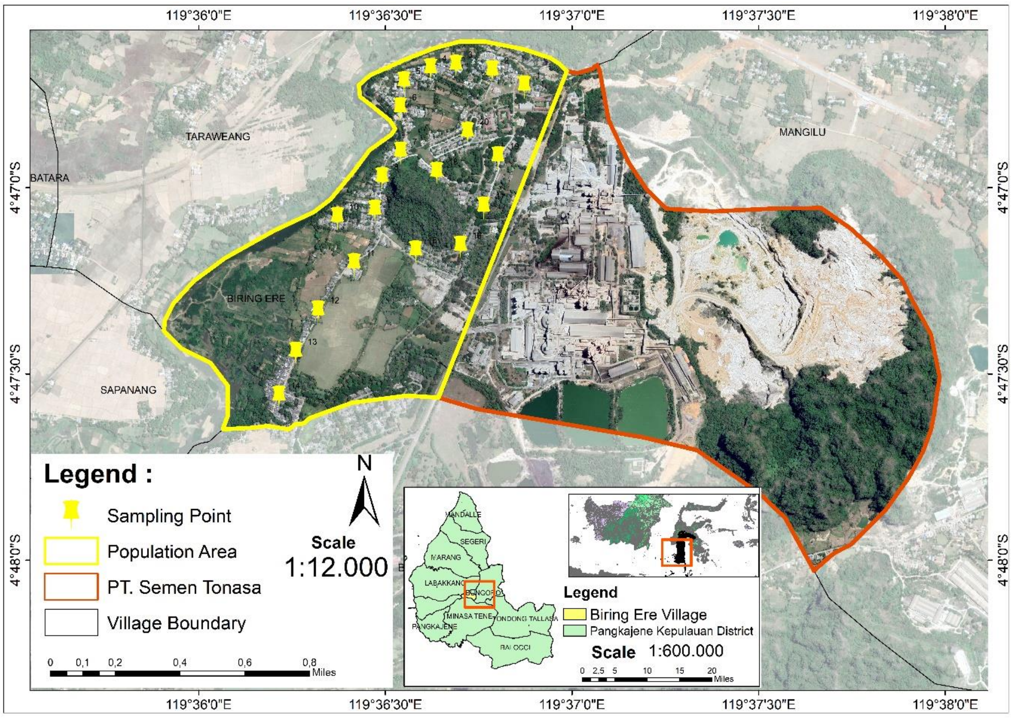


Figure 2. Map of research locations (Source: Primary data, 2024).

Potential distribution of lead in well water

Inverse Distance Weighted (IDW) interpolation is one of the spatial interpolation methods that assume that each input point has a local influence that decreases with distance. This method is generally influenced by the inverse distance obtained from mathematical equations and we can adjust the relative influence of the sample points. The power value in IDW interpolation determines the influence on the input points, where the influence will be greater at closer points resulting in a more detailed surface.

Figure 3 illustrates the potential distribution of lead in the well water of Biring Ere Village residents based on several sampling results at 20 points. The dotted line is the road that separates the residential area and PT Semen Tonasa area. The sampling points are located in the west of the figure so that the potential distribution only describes the potential in the resident area, not in the company area separated by the dotted line in the figure. In Figure 3, it can be seen that the distribution of heavy metal Pb concentration in well water in Biring Ere Village varies.

Wind direction and wind speed

Wind plays a major role in the dispersion of pollutants. These pollutant particles will then move in the direction of the wind. The strength of the wind also affects the speed at which pollutants spread from the source [31].

The dominant wind direction at the research site blows westward from the measurement point. This can be an indicator that the wind blows from the direction of the company toward the residential area of Biring Ere Village.

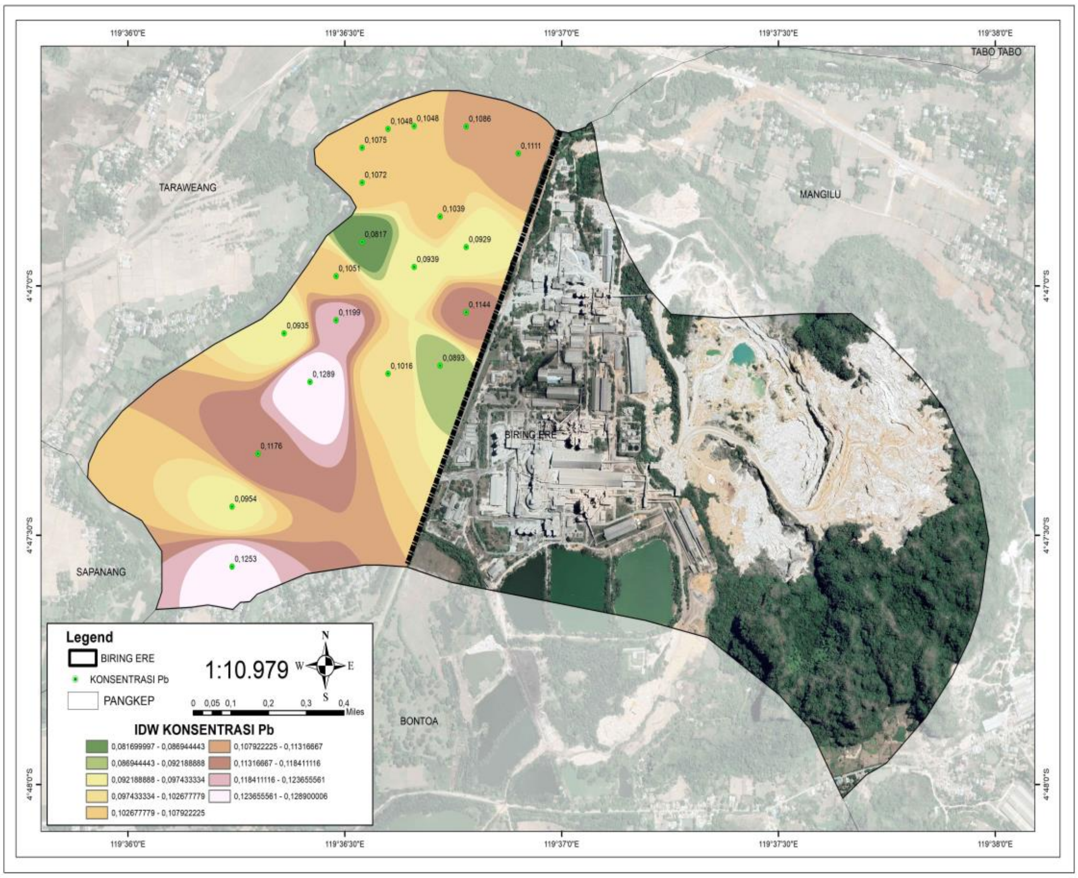
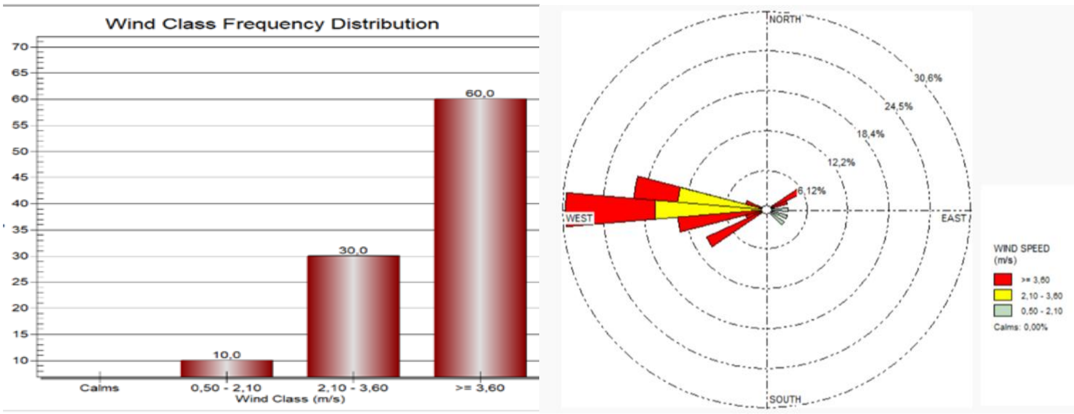


Figure 3. Potential distribution of heavy metal Pb in well water of Biring Ere Village community (Source: Primary data, 2024).



(a) **(b)**

Figure 4. (a) Wind rose and (b) frequency distribution of wind classes (Source: Primary Data, 2024).

Table 2. Concentration of lead in well water, n = 40

Heavy Metal	*Concentration In Well Water*			
	Min	Max	Mean	SD
Pb	0.0817	0.1289	0.1054	0.012155

The distribution of wind classes from January to June 2024 primarily consists of winds with a speed of 2.10-3.60 m/s, accounting for 30%, and winds with a speed of 0.50-2.10 m/s, accounting for 10%.

Figure 4 (a) shows the wind direction for 6 months around the cement industry, where the dominant wind direction at the study site is to the west. Meanwhile, Figure 4 (b) shows the frequency distribution of wind classes, where most of them are in the 2.10-3.60 m/s wind class.

Risk assessment

Concentration of lead in well water

Lead (Pb) concentration is the concentration of heavy metals found in drinking water sources expressed in mg/l. Heavy metal concentrations were measured in the well water of residents living in Biring Ere Village using random sampling techniques; measurements were made on 20 wells in Biring Ere Village.

Based on the analysis conducted at the chemical laboratory of PT Sucofindo using the ICP (Inductively Coupled Plasma) method, it shows that the average measurement results of heavy metal Pb in each sample detected all exceed the predetermined threshold value. A similar study [15] showed that the concentration of heavy metal Pb in the well water of residents living around the Bosowa cement industry has exceeded the established quality standards.

Table 1 indicates that the concentration of Pb in the sampled well water varied, with the lowest being 0.0817 and the highest being 0.1289. These varying concentrations can be caused by many factors, such as the direction of the wind that carries pollution from the cement industry and the proximity of the well location to the cement industry.

Exposure duration, intake rate, and exposure frequency of lead

Exposure duration, intake rate, and exposure Frequency were obtained from questionnaires and interviews directly with people living in the research location. Based on Table 2 and data obtained from respondents, the highest exposure duration was 12 years and the lowest was 7 years. At the intake level, the results varied, with the highest value of 2 mg/l/day and the lowest of 1.2 mg/l/day. Likewise, based on the results of the frequency of exposure to well water containing Pb, the longest is 365 days per year, and the lowest is 350 days per year.

Based on the data in Table 3 obtained from adult respondents, the highest exposure duration was 65 years, and the lowest was 18 years. At the intake level, the results varied, with the highest value of 3.0 mg/l/day and the lowest of 2.0 mg/l/day. Furthermore, based on the results of the frequency of exposure to well water containing lead, the longest is 365 days per year, and the lowest is 350 days per year.

Hazard identification

Hazard identification in research is the initial step in ARKL which is used to find out specifically what risk agents have the potential to cause health problems when the body is exposed. Community drinking water sampling locations were taken from community well water in Biring Ere Village that met the predetermined inclusion criteria. Determination of sampling locations, as many as 20 well points scattered throughout Biring Ere Village, with each sample of 250 ml. As seen in Figure 5, almost all wells in Biring Ere Village do not have covers, and the walls of the wells found in this study are not too high, making it easier for pollution to enter and contaminate the water contained in the well. Well water sampling locations were taken from Biring Ere Village. The sampling location was determined as 20 well points in Biring Ere Village. The concentration of lead in well water is presented in Table 1.

Table 3. Exposure duration, intake rate, and exposure frequency lead in child respondents, n = 40

	Min	Max	Mean
Exposure Duration (year)	7	12	9.25
Intake Rate	1.2 mg/l/day	2 mg/l/day	1.8 mg/l/day
Exposure Frequency	350 day/year	365 day/year	355 day/year

Table 4. Exposure duration, intake rate, and exposure frequency of lead in adult Respondents, n = 40

	Min	Max	Mean
Exposure Duration	18 year	65 year	47.1 year
Intake Rate	2.0 mg/l/day	3.0 mg/l/day	2.6 mg/l/day
Exposure Frequency	350 day/year	365 day/year	355 day/year

Figure 5. Types of dug wells used by the community (Source: Primary data, 2024).

Exposure analysis

The exposure analysis calculated the Intake (I) value of each risk agent taken from drinking water sources at the study site. The minimum, maximum, and mean values of real-time Intak are presented in Table 5.

Based on Table 5, the value of non-carcinogenic intake in adult and child respondents with the duration of exposure to heavy metal Pb in real time still meets the standard or does not exceed the Slope Factor (SF) of the reference dose.

Dose response analysis

A dose-response analysis was conducted by finding the SF values of the risk agents that were the focus of the EHRA. Slope factor (SF) values based on US-EPA (1998) were obtained for Pb (0.085 mg/kg/day). The Risk Quotient (RQ) values of these dietary exposure risk agents were then used to determine the magnitude of the public health risk.

Risk level characteristics

Based on Table 6, it is known that the value of the level of non-carcinogenic risk or RQ value in heavy metal Pb, for the duration of realtime exposure in adult and child respondents, the average RQ value is RQ ≥ 1, so it is categorized as risky in the population that consumes it.

Risk level category

The risk level of Pb in the ingestion/oral exposure pathway is determined by RQ values.

The results of the RQ calculation of Pb exposure with an RQ value > 1 means that the contaminant has a non-carcinogenic risk on the consumption/oral route. There were 17 adult respondents (85%) in the unsafe category, while 20 children respondents (100%) were in the unsafe category (Table 7).

The determination of safe limits of heavy metal concentrations in drinking water sources exposure is presented in Table 8.

Table 5. Intake values of adult and child respondents for real time exposure duration in 2024

Heavy Metals	Intake (mg/L/day)			Desc.
	Children			
	Min	Max	Mean	
Pb	0.00426	0.00818	0.00599	MS
Heavy Metals	Intake (mg/L/day)			Desc
	Adult			
	Min	Max	Mean	
Pb	0.00388	0.00605	0.00463	MS

Description: MS (Meets Standard), DMS (Does Not Meet Standard).
**Note: Pb 0.085 mg/kg/day.*
Source: Primary Data, 2024.

Table 6. Real-time Min, Max, and Mean RQ values for Pb in Biring Ere Village

Heavy Metals	Risk Quotient (RQ)						Desc.
	Adult			Children			
	Min	Max	Mean	Min	Max	Mean	
Pb	0.84646	1.51450	1.15972	1.06565	2.04657	1.49762	UC

Description: RQ ≥ 1 (Unacceptable, RQ < 1 (Acceptable).
Source: Primary data, 2024.

Table 7. Distribution of respondents by real time non-carcinogenic risk level category in drinking water sources of Biring Ere Villagers (N=40)

Age group	Big Risk	Risk Quotient (RQ) Pb
Children	RQ>1	20 (100%)
	RQ≤1	0
Adult	RQ>1	17 (85%)
	RQ≤1	3 (15%)

Table 8. Determination of safe limits of heavy metal concentrations of lead in adult and child respondents in Biring Ere Village

Category	HM	K	SF	Wb (kg)	tavg	IR	fE	Dt	Safe limit (mg/L)
Adult	Pb	10^{-4}	0.085	51.8	25550	2.2	365	70	4×10^{-2}
Children	Pb	10^{-4}	0.085	24.7	25550	1.3	365	70	3×10^{-2}

Source: Primary data, 2024.

Table 9. Determination of safe consumption amounts of heavy metal concentrations in drinking water sources in communities in Biring Ere Village

Category	HM	K	SF	Wb (kg)	tavg	CW	fE	Dt	safe consumption (mg/L)
Adult	Pb	10^{-4}	0.085	51.8	25550	0.10537	365	70	1.135
Children	Pb	10^{-4}	0.085	24.7	25550	0.10537	365	70	0.276

Source: Primary data, 2024.

Risk management

Risk management is an advanced stage of Environmental Health Risk Assessment. This section is related to the EHRA formula specifically for risk reduction at the community level. Based on the heavy metal concentrations of the well water samples that are above the predetermined threshold value, the Risk Quotient (RQ) value which indicate that well water can cause health risks to the community around the cement industry, risk management needs to be carried out. Based on Table 8, the concentration of heavy metal pb falls into the unsafe category so the determination of the safe limit of non-carcinogenic risk in adult respondents, the concentration of heavy metal Pb is 4×10^{-2} mg/L and in children is 3×10^{-2} mg/L.

Based on the risk characteristics, risk management options can be formulated to minimize the RQ by manipulating (changing) the values of the exposure factors so that the intake is smaller or equal to the toxicity reference dose, reducing the concentration of the risk agent if the pattern and timing of consumption cannot be changed.

Based on Table 6, heavy metal Pb was unsafe concentrations in adult and child respondents, then the determination of the safe limit for non-carcinogenic risk in adult respondents the concentration of heavy metal Pb is 4×10^{-2} mg/L and in children Pb is 3×10^{-2} mg/L.

Another effort that can be made to reduce or manipulate the intake value to be equal to the RfD is to reduce the amount of consumption or in other words reduce the intake rate. The determination of the safe amount of consumption in drinking water sources for 70 years in adult respondents is 1.135 mg/L, while safe consumption in child respondents is 0.276 mg/L.

Conclusion

Besides the environmental risks, the magnitude of risks to public health around the cement industry needs to be calculated using the health risk assessment method. Previous studies have only focused on environmental impacts and not on the health risks that arise in communities living around the cement industry. This study also confirms that in addition to air parameters, well water consumed can also be a pathway for heavy metal contamination and pose a health risk to the community. The results of laboratory analysis showed that Pb concentrations were above the established quality standards. Therefore, the calculation of the risk quotient value shows that all 40 respondents have a non-carcinogenic risk.

Both the community and the cement industry need to manage risk. At the community level, risk reduction involves calculating the safe concentration limit of risk agents and determining the safe consumption amount. As for industry, periodic monitoring of exhaust emissions and liquid waste generated during the production process is necessary to ensure that emissions meet established environmental standards and the use of the latest technology in waste management so as not to pollute community drinking water sources.

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Conflict of Interest

No potential conflict of interest was reported by the authors in this study.

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