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Risk Assessment of Cadmium (Cd) and Chromium (Cr) Exposure from Bosowa Cement Industry Emissions to Water Sources Utilized in Maros

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Abstract The industry is a source of heavy metal pollution and, in the long term, can negatively impact the environment through air, soil and water. If ingested in excess and over an extended period, the effects of heavy metal contamination on well water in the vicinity of the cement industry will result in health issues. **Objective:** This study aimed to determine the concentration levels of heavy metals Cd and CrVI in well water, exposure duration, intake rate and frequency of exposure to Cd and CrVI in people who use well water around the Bosowa Cement Industry. **Method:** This study used purposive sampling method, while the number of samples in this study was calculated using the slovin formula which resulted in 80 human samples and 40 well water sampling points. This type of research is a quantitative descriptive study using the Environmental Health Risk Analysis (EHRA) method, where intake, excess cancer risk (ECR), and risk management analysis were carried out in this study. If the contamination has a carcinogenic risk then risk management is required based on ECR>4 calculations. **Result:** As a result, the environmental health risks from exposure to heavy metals Cd and CrVI are as follows: The ECR value of Cd in adult respondents is between $1x10^{-4}$-$2x10^{-3}$, while in children respondents is between $1x10^{-4}$-$3x10^{-3}$. The ECR value of CrVI for adult respondents is between $3x10^{-6}$-$6x10^{-5}$, while for children, respondents are between $4x10^{-6}$-$9x10^{-5}$. Risk management can be done by determining the safe consumption limit and the amount of safe consumption.

Keywords EHRA, Cadmium, Chromium, Risk Management, Cement Industry

1. Introduction

Heavy metal pollution in the environment harms humans animals, plants, and the environment [1]. Pollution from human activities contributes more than pollution from natural activities [2]. Quarry is an unorganized sector that involves various processes that produce dust particles of silica and heavy metals [3].

Heavy metals provide the greatest threat to human health when it comes to water pollution [4]. At low levels, some heavy metals are generally needed by living organisms for their growth and development. Conversely, in large concentrations, heavy metals alter their characteristics and turn poisonous. Heavy metals are elements that have a potentially toxic power and the ability to accumulate in human organs [5]. Industry is one source of heavy metal contamination [6]. Emissions of both solid and gaseous pollutants from cement factories are regarded as environmental contaminants that can lead to significant issues if not adequately recognized and monitored [7].

Cement production involves several important components and stages. The components of cement production before the production process consist of the main raw materials of limestone and clay as well as additional raw materials such as silica sand, iron ore, and gypsum. The manufacturing process itself consists of several stages, namely: mining and crushing, grinding and mixing, heating in a rotary kiln, cooling, final grinding, and packaging and distribution [8]. In the cement industry, the surrounding community needs to be involved in environmental impact consultations before the mining and production process begins. The cement industry is required to conduct an environmental impact assessment (EIA), which is expected to be able to commit to sustainable mining practices [9].

High concentrations of heavy metals in the environment (water, soil and air) can be very dangerous [10]. This can cause environmental damage and increase the toxicity and bioaccumulation of the metal itself. Heavy metals typically possess poisonous qualities that can be detrimental to living organisms, while certain heavy metals are required in small quantities. Directly or indirectly, the toxicity of pollutants triggers pollution in the surrounding environment [11].

One of the heavy metals that is harmful to health if contained in water is (CrVI). CrVI is carcinogenic to the body [12]. CrVI can enter water bodies in two ways, namely natural and non-natural ways. The entry of CrVI naturally, such as erosion or erosion of mineral rocks and dust or CrVI particles in the air, will be brought down by rainwater. The entry of CrVI in a non-natural way is more related to human activities, such as industrial and household waste disposal into water bodies [13].

Like CrVI, Cd is also a toxic and non-essential heavy metal [14]. When Cd is inhaled with air, it will cause more severe poisoning than if this metal is ingested through the digestive tract. Acute poisoning due to Cd mainly occurs due to inhalation of dust and smoke containing Cd, especially Cadmium oxide (CdO) [15]. Cd is very dangerous to health because the acute toxic effects of the element are very bad, affecting the human nervous system and kidney systems. Cd poisoning is both acute and chronic [16]. The body systems that can be damaged are the kidneys, lungs, blood deficiency, and bone fragility, affecting the reproductive system and its organs, and Cd metal is thought to be one of the causes of cancer in humans [1].

In the cement sector the two major ways that workers are exposed to heavy metals at work are through inhalation and dermal absorption [17]. In a similar vein, over time, the toxicity of surplus materials from a facility affects homes close to industrial activities. One of the body's most susceptible organs to heavy metals seeping through to the surface is the skin. The degree, kind, and length of exposure to heavy metals determine the short- and long-term occurrence of skin conditions and disease indicators [18].

Bosowa's cement sector, in particular, has the potential to have a large negative influence on the environment and public health due to the pollution that heavy metals and other pollutants can cause in the water. Heavy metal contamination, such as that caused by Cr and Cd, can deteriorate groundwater quality to the point where it is dangerous for aquatic life, irrigation, and human consumption. Proteinuria, or the presence of protein in the urine, is a symptom of kidney damage that can be brought on by prolonged exposure to Cd. Hexavalent chromium (Cr) (Cr (VI)) is carcinogenic. Cr(VI) exposure may raise the risk of developing lung cancer as well as other malignancies [19].

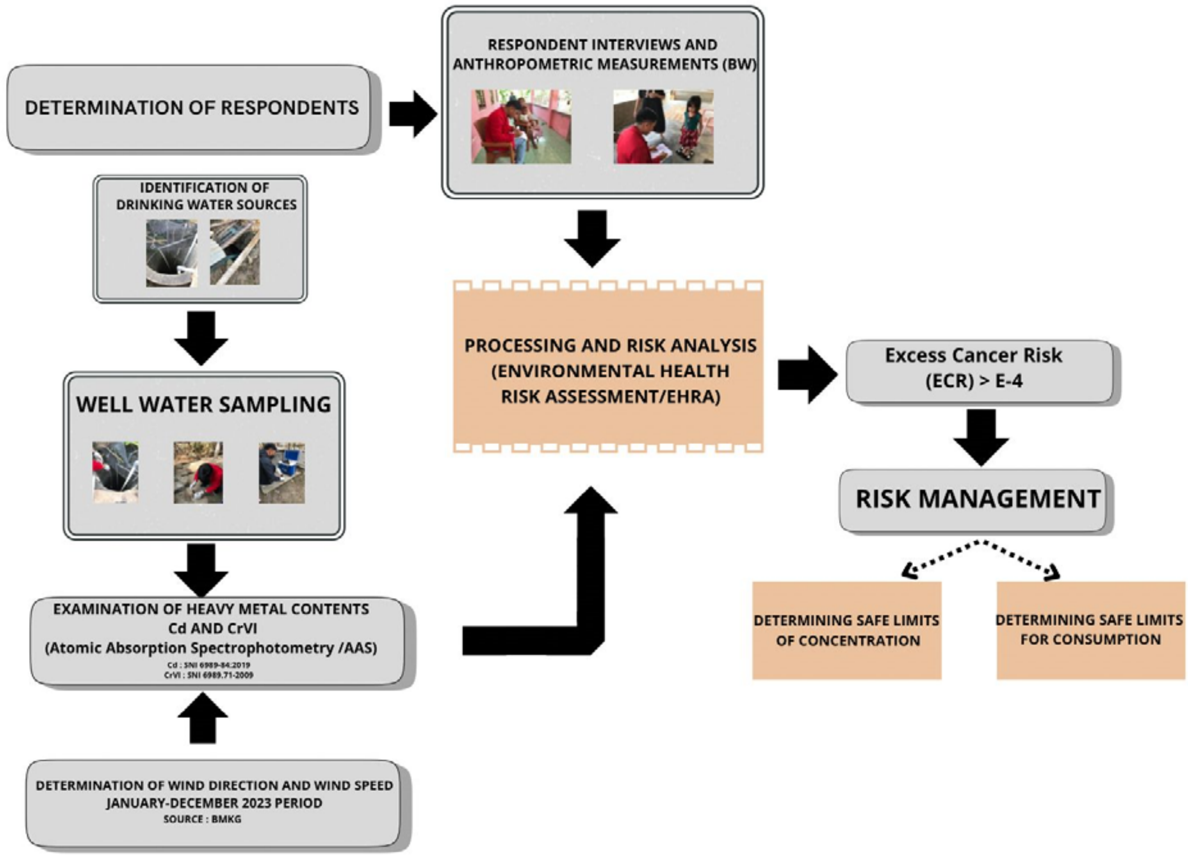
This study spesifically focuses on concentration levels of heavy metals Cd and CrVI in well water, exposure duration, intake rate and frequency of exposure to Cd and CrVI in people who use well water around the Bosowa Cement Industry.

2. Materials and Methods

2.1. Type and Design of Research

The research methodology employed is analytical observational research, specifically utilizing an Environmental Health Risk Analysis (EHRA) technique. This strategy is used to evaluate and quantify the extent of human health risks resulting from exposure to the heavy metals Cadmium (Cd) and Chromium VI (CrVI). The research began with determining respondents and conducting interviews regarding well water consumption and anthropometric measurements. Next, well water samples are taken for laboratory examination and data processing to analyze health risks that will arise.

In Figure 1 we can see the flow in this study starting with the determination of respondents and the determination of water sampling points. In respondents who have been determined, body weight measurements and interviews are carried out regarding the consumption of well water which is the research sample. As for the source of well water which is the research sample, it is taken and then taken to the laboratory for further analysis of the heavy metal content of cadmium and chromium. The next stage is to calculate the environmental health risk analysis which is then continued with risk management.



(Source: Primary Data, 2024)

Figure 1. Research Flow Chart

2.2. Population and Sample

To determine the extent of the dangers to human health associated with exposure to the heavy metals CrVI and CD, analytical observational research using an Environmental Health Risk Analysis (EHRA) technique is the sort of research that is used. The first steps in the research were to identify participants and carry out interviews about anthropometric measurements and well water intake. Subsequently, 40 well water samples were collected in 300 ml plastic bottles and analyzed at a lab.

The research locations in this study are shown in Figure 2 which are two villages located in ring 1 of PT Semen Bosowa where the two villages, Tukamasea Village and Baruga Village, are the two villages most exposed to pollution caused by industrial processes at PT Semen Bosowa.

2.3. Research Instruments

2.3.1. Questionnaires and Interviews

Questionnaires and interviews in this study were used to obtain data on respondents' characteristics, consumption rate (consumption time, consumption frequency, consumption duration) in a day, body weight and identification data such as name, age, and gender, how well water is processed before consumption and subjective health complaints felt by respondents.

2.3.2. Risk Analysis and Environmental Health Risk

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

Description:
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 carcinogens, AT=ED x 365 days)*

$$ECR = \ \ I\ \ x\ \ SF \tag{2}$$

Description:
ECR = Excess Cancer Risk
SF = Risk agent reference value (Slope Factor)
I = Intake (exposure)

Once an environmental health risk analysis has been completed and an Excess Cancer Risk (ECR) value > E-4 has been obtained, a risk management strategy must be implemented. This involves figuring out safe intake limits and amounts.

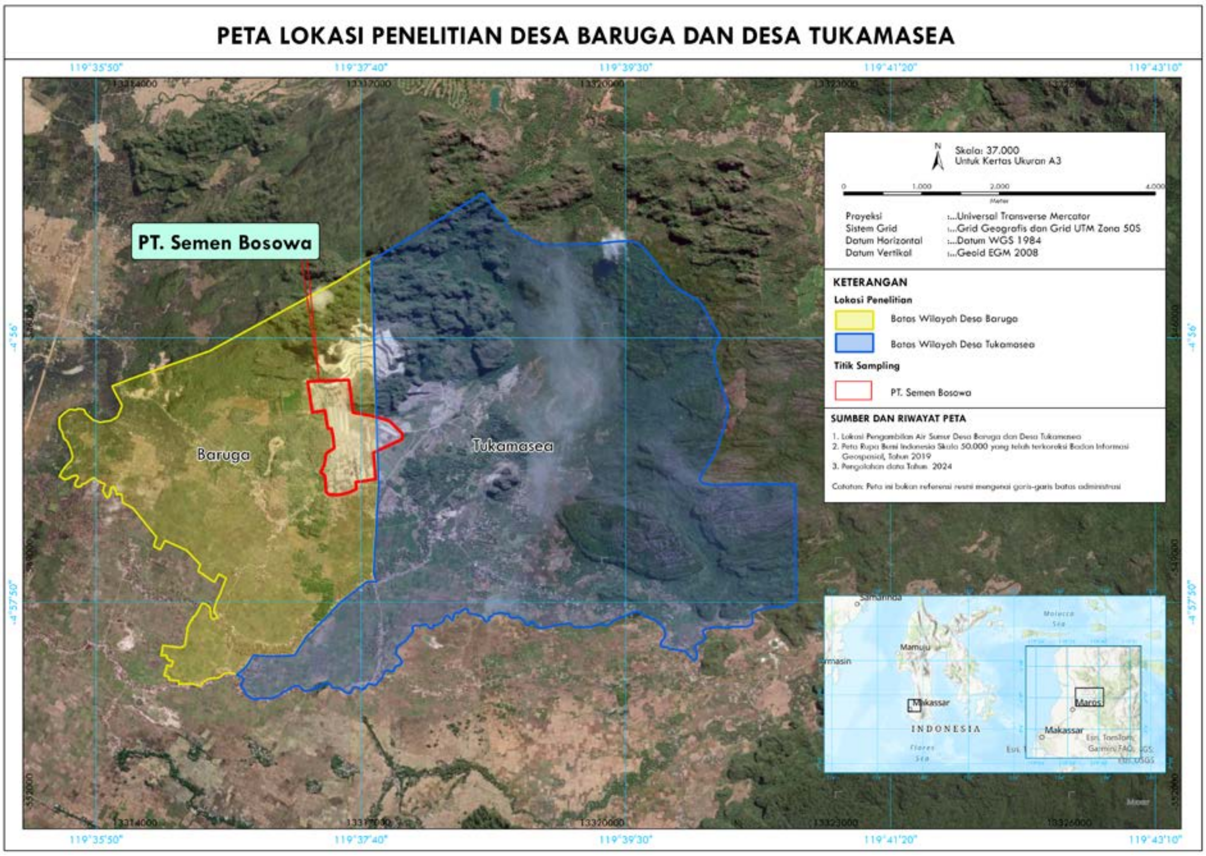


Figure 2. Map of Research Locations

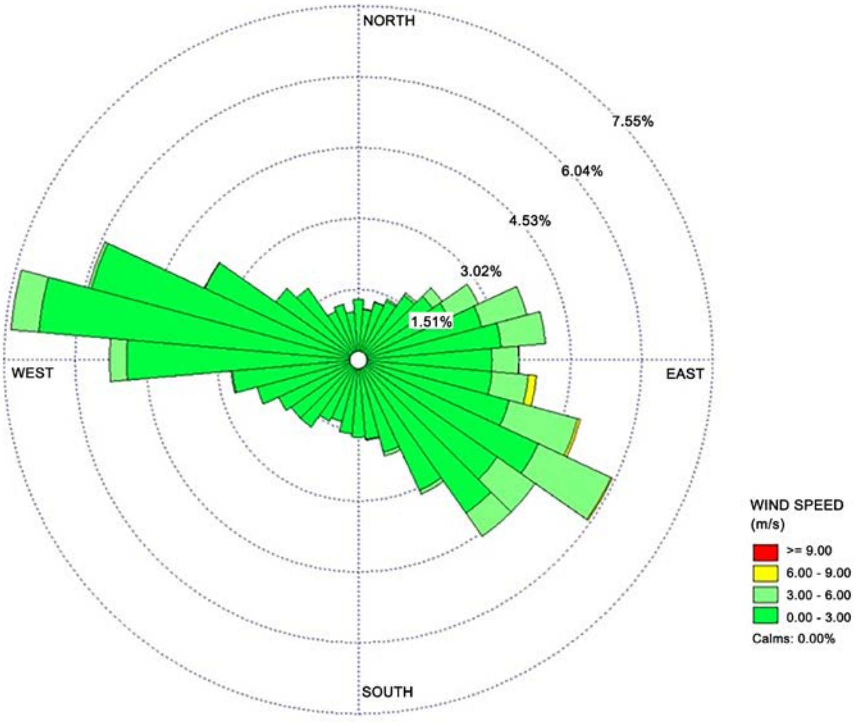
3. Result and Discussion

3.1. Wind Direction and Wind Speed

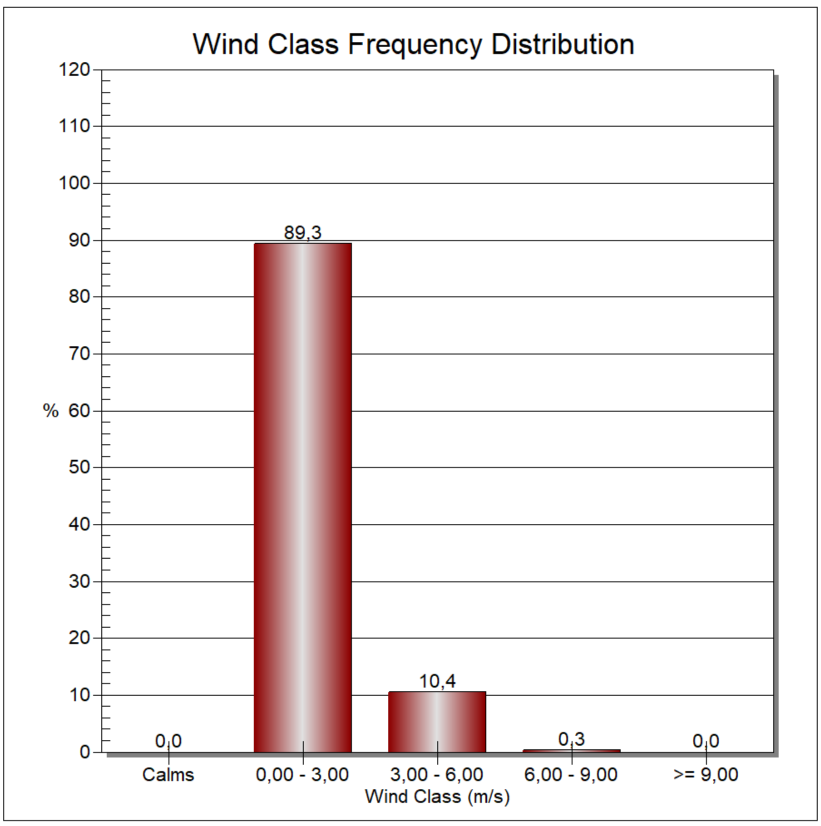
Wind plays a major role in pollutant dispersion. These pollutant particles will then move in the direction of the wind. The strength of the wind also affects the speed of pollutant dispersion from the source (Hasibuan et al., 2018).

The dominant wind directions at the study site are west and southeast. The west direction of the contamination source point is Baruga Village, while the southeast direction is Tukamasea Village. The distribution of wind classes in 2023 is mostly in the 0.00-3.00 m/s class by 89.3%, in the 3.00-6.00 m/s class by 10.4% and in the 6.00-9.00 m/s wind class by 0.3.

Figure 3 (a) shows the wind direction for 12 months around PT Semen Bosowa, where the dominant wind direction at the research location is west and southeast. Meanwhile, Figure 3 (b) shows the frequency distribution of wind classes, which is found to be mostly in the 0.00-3.00 m/s wind class.



(a)



(b)

Figure 3. (a) Wind rose 1 year 2024 (b) Frequency distribution of wind classes

3.2. Risk Assessment

3.2.1. Concentration Of Cr And Cd Heavy Metals In Well Water, Exposure Duration, Intake Rate, And Exposure Frequency Of Cd And Cr

The analysis revealed variations in the concentrations of Cd and Cr in each well. The study provides the concentration levels of Cd and Cr in well water samples.

Table 1 shows that the concentration values of the heavy metals Cr, which are lowest in well water, which is the study's sample, are 0.001 and greatest in 0.005. Regarding CrVI concentration values, the lowest is 0.005, and the maximum is 0.01.

Table 1. Concentration of CrVI and Cd Heavy Metals in Well Water

Heavy Metal	*Concentration In Well Water*		
	Min	Max	Mean
Cd	0,001	0,005	0,002
CrVI	0,005	0,01	0,0067

Based on Table 2 and the data obtained from respondents, the duration of exposure found the highest result for 50 years and the lowest for 5 years. At the intake level, varying results were found, with the highest value of 3 mg/l/day and the lowest of 2 mg/l/day. And based on the results of the frequency of exposure to well water containing Cd and CrIV, the longest is 365 days per year, and the lowest is 350 days per year.

Table 2. Exposure Duration, Intake Rate, And Exposure Frequency Of Cd And Cr

	Min	Max	Mean
Exposure Duration	5 year	50 year	26,17 year
Intake Rate	2 mg/l/day	3 mg/l/day	3 mg/l/day
Exposure Frrequency	350 day/year	365 day/year	355 day/year

3.2.2. Hazard Identification

Identification is carried out on well water used by the community, the criteria for wells identified are the type of dug well with an open well condition and the potential to be contaminated with heavy metals from emissions from the Bosowa Cement Industry.

Water sources containing heavy metals pose a substantial threat to public health. These contaminants can be found in various water environments, including river water, surface water, groundwater, agricultural water, and community drinking water sourced from wells. Several international studies have been conducted to assess the magnitude of risk posed by these contaminants and their impact on public health (Table 3).

Based on previous research data in Table 3, we can see that many heavy metal pollution figures still pollute various water sources that exceed the predetermined limits.

Table 3. Risk level related to heavy metals and microbes in previous studies

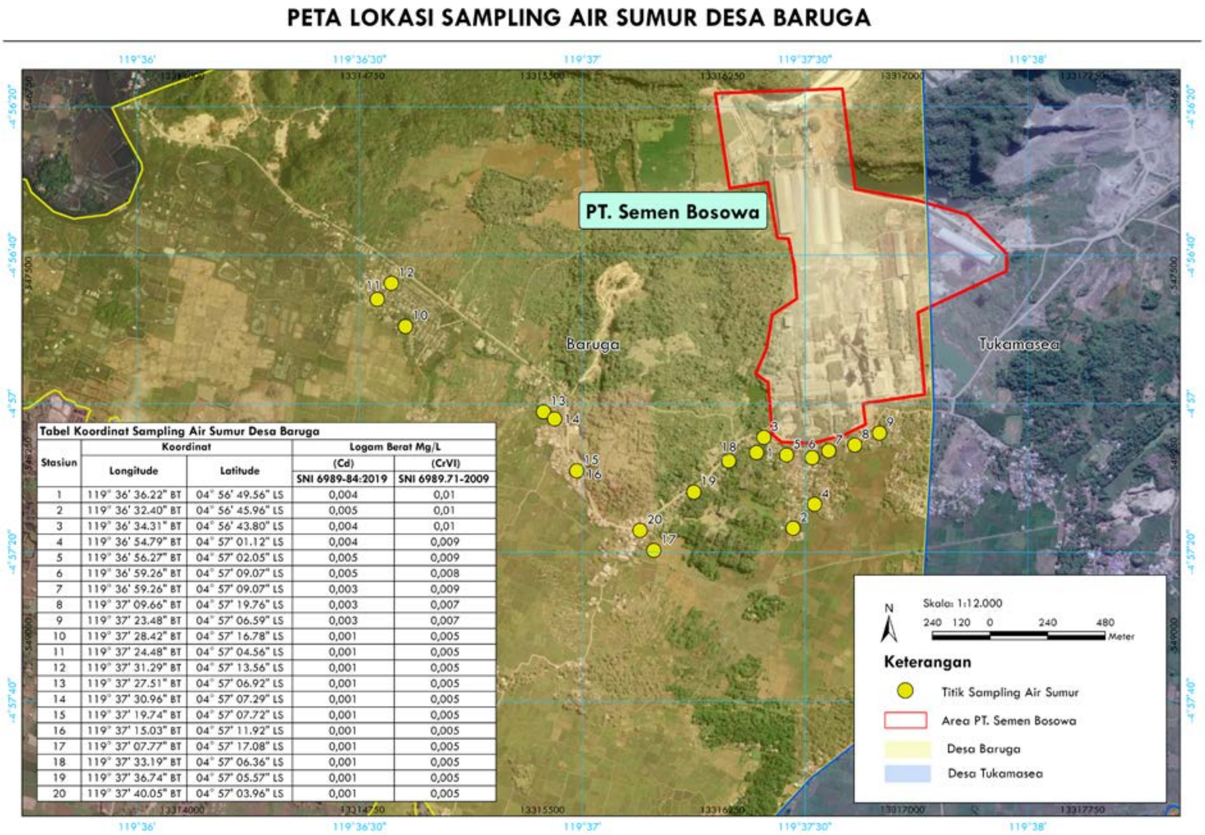
Kind of sampling water	Metal	Reference level of risk	Measured concentration	RQ /ECR	Conclusion	Area	Source
Sea Water	Pb	0.008 mg/L	0.007	$>10^{-4}$	Risk	Tangerang district littoral	[20]
	Cd	0.001 mg/L	0.00013	$>10^{-4}$	Risk	Tangerang district littoral	
	Zn	0.05 mg/L	0.014	$>10^{-4}$	Risk	Tangerang district littoral	
Drinking water	Pb	0,01 mg/L	0.60 ± 0.12	$>10^{-4}$	Risk	Northeast Iran	[21]
	Ni	0,07 mg/L	1.79 ± 0.915	$>10^{-4}$	Risk	Northeast Iran	
	Cr	0,03 mg/L	4.91 ± 6.33	$>10^{-4}$	Risk	Northeast Iran	
	Hg	0,05 mg/L	0.04 ± 0.02	$>10^{-4}$	Risk	Northeast Iran	
	As	0,05 mg/L	0.17 ± 0.045		Risk	Northeast Iran	
Surface water	Zn	0,01 mg/L	0.06	$>10^{-4}$	Risk	Kenya	[22]
	Cu	0,07 mg/L	0.2	$>10^{-4}$	Risk	Kenya	
	Pb	0,01 mg/L	0.01	$>10^{-4}$	Risk	Kenya	
Ground water	As	0,05 mg/L	0.0002	$>10^{-4}$	Risk	North Central Nigeria	[23]
	Cd	0,01 mg/L	0.00007	$>10^{-4}$	Risk	North Central Nigeria	
	Cr	0,03 mg/L	0.0039	$>10^{-4}$	Risk	North Central Nigeria	

As shown in Figure 4, almost all residents' wells in Baruga Village and Tukamasea 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 wells. Community drinking water sampling locations were taken from Baruga Village and Tukamasea Village community well water. The sampling location was determined as 40 well points, namely 20 water samples in Baruga Village and 20 in Tukamasea Village. Heavy metals Cd and CrVI concentrations in well water are presented in Figures 5.

Figure 5 shows that the concentrations of Cd and CrVI in Baruga Village vary at each well sample point. The highest Cd concentration at points 2,5 and 6 is 0.005 mg/L, and the highest CrVI concentration at points 1,2 and 3 is 0.010 mg/L. The levels of Cd and CrVI in Baruga Village are higher than the maximum allowable amounts stated in Regulation 492 of 2010 by the Minister of Health of the Republic of Indonesia. Specifically, the concentration of Cd exceeds 0.003 mg/L and the concentration of CrVI exceeds 0.05 mg/L.

Figure 6 shows that the concentration of Cd and CrVI in Tukamasea Village varies at each well sample point. The highest Cd concentration at points 1, 2, and 4 is 0.004 mg/L, and the highest CrVI concentration at points 1, 2, 3, 4, and 6 is 0.010 mg/L. The levels of Cd and CrVI in Tukamasea Village beyond the permissible limits are set by Regulation of the Minister of Health of the Republic of Indonesia Number 492 of 2010, namely (Cd=0.003 mg/L) (CrVI=0.05 mg/L).

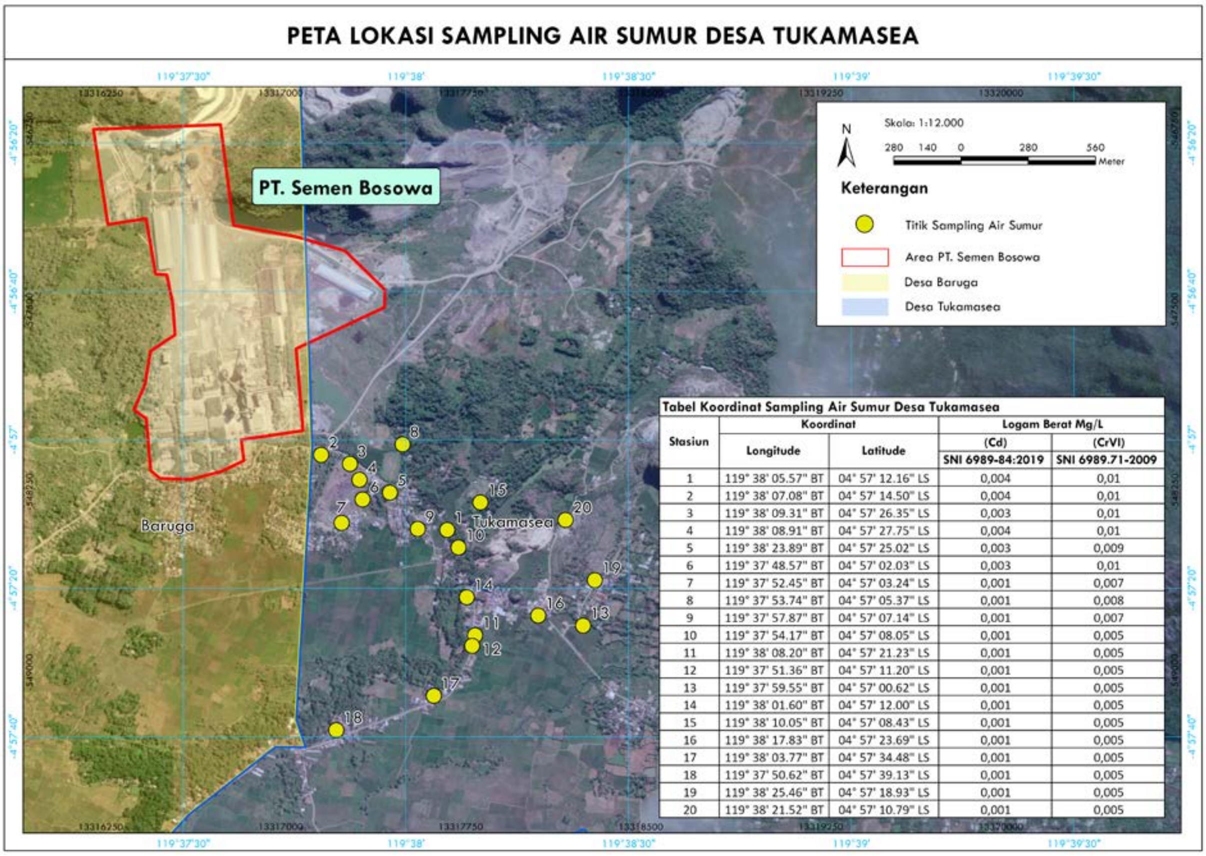
Figure 4. Types of dug wells used by the community



Tabel Koordinat Sampling Air Sumur Desa Baruga

Stasiun	Koordinat		Logam Berat Mg/L	
	Longitude	Latitude	(Cd) SNI 6989-84:2019	(CrVI) SNI 6989.71-2009
1	119° 36' 36.22" BT	04° 56' 49.56" LS	0,004	0,01
2	119° 36' 32.40" BT	04° 56' 45.96" LS	0,005	0,01
3	119° 36' 34.31" BT	04° 56' 43.80" LS	0,004	0,01
4	119° 36' 54.79" BT	04° 57' 01.12" LS	0,004	0,009
5	119° 36' 56.27" BT	04° 57' 02.05" LS	0,005	0,009
6	119° 36' 59.26" BT	04° 57' 09.07" LS	0,005	0,008
7	119° 36' 59.26" BT	04° 57' 09.07" LS	0,003	0,009
8	119° 37' 09.66" BT	04° 57' 19.76" LS	0,003	0,007
9	119° 37' 23.48" BT	04° 57' 06.59" LS	0,003	0,007
10	119° 37' 28.42" BT	04° 57' 16.78" LS	0,001	0,005
11	119° 37' 24.48" BT	04° 57' 04.56" LS	0,001	0,005
12	119° 37' 31.29" BT	04° 57' 13.56" LS	0,001	0,005
13	119° 37' 27.51" BT	04° 57' 06.92" LS	0,001	0,005
14	119° 37' 30.96" BT	04° 57' 07.29" LS	0,001	0,005
15	119° 37' 19.74" BT	04° 57' 07.72" LS	0,001	0,005
16	119° 37' 15.03" BT	04° 57' 11.92" LS	0,001	0,005
17	119° 37' 07.77" BT	04° 57' 17.08" LS	0,001	0,005
18	119° 37' 33.19" BT	04° 57' 06.36" LS	0,001	0,005
19	119° 37' 36.74" BT	04° 57' 05.57" LS	0,001	0,005
20	119° 37' 40.05" BT	04° 57' 03.96" LS	0,001	0,005

Figure 5. Map of Baruga Village Well Water Sampling Location



Tabel Koordinat Sampling Air Sumur Desa Tukamasea

Stasiun	Koordinat		Logam Berat Mg/L	
	Longitude	Latitude	(Cd) SNI 6989-84:2019	(CrVI) SNI 6989.71-2009
1	119° 38' 05.57" BT	04° 57' 12.16" LS	0,004	0,01
2	119° 38' 07.08" BT	04° 57' 14.50" LS	0,004	0,01
3	119° 38' 09.31" BT	04° 57' 26.35" LS	0,003	0,01
4	119° 38' 08.91" BT	04° 57' 27.75" LS	0,004	0,01
5	119° 38' 23.89" BT	04° 57' 25.02" LS	0,003	0,009
6	119° 37' 48.57" BT	04° 57' 02.03" LS	0,003	0,01
7	119° 37' 52.45" BT	04° 57' 03.24" LS	0,001	0,007
8	119° 37' 53.74" BT	04° 57' 05.37" LS	0,001	0,008
9	119° 37' 57.87" BT	04° 57' 07.14" LS	0,001	0,007
10	119° 37' 54.17" BT	04° 57' 08.05" LS	0,001	0,005
11	119° 38' 08.20" BT	04° 57' 21.23" LS	0,001	0,005
12	119° 37' 51.36" BT	04° 57' 11.20" LS	0,001	0,005
13	119° 37' 59.55" BT	04° 57' 00.62" LS	0,001	0,005
14	119° 38' 01.60" BT	04° 57' 12.00" LS	0,001	0,005
15	119° 38' 10.05" BT	04° 57' 08.43" LS	0,001	0,005
16	119° 38' 17.83" BT	04° 57' 23.69" LS	0,001	0,005
17	119° 38' 03.77" BT	04° 57' 34.48" LS	0,001	0,005
18	119° 37' 50.62" BT	04° 57' 39.13" LS	0,001	0,005
19	119° 38' 25.46" BT	04° 57' 18.93" LS	0,001	0,005
20	119° 38' 21.52" BT	04° 57' 10.79" LS	0,001	0,005

Figure 6. Map of Baruga Village Well Water Sampling Location in 2024

3.2.3. 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 Realtime Carcinogenic Intake (I) are presented in Table 4 as follows:

Table 4. Carcinogenic Intake Values of Adult and Child Respondents for Realtime Exposure Duration in 2023

Heavy Metals	Intake (mg/L/day)			Desc.
	children			
	Min	Max	Mean	
Cd	$7{,}9x10^{-6}$	$1{,}8x10^{-4}$	$4{,}7x10^{-5}$	MS
CrVI	$3{,}3x10^{-5}$	$4{,}6x10^{-4}$	$1{,}7x10^{-4}$	MS
Heavy Metals	Intake (mg/L/day)			Desc.
	adult			
	Min	Max	Mean	
Cd	$7x10^{-6}$	$1x10^{-4}$	$3x10^{-5}$	MS
CrVI	$2x10^{-5}$	$3x10^{-4}$	$1x10^{-4}$	MS

Description : MS (Meets Standard), DMS (Does Not Meet Standard)
*Note : CSF Cd 15 mg/kg/day and CrVI 0.5 mg/kg/day.
Source : Primary Data, 2024

Table 5. Real-time Min, Max and Mean ECR Values in Baruga and Tukamasea Villagers

Heavy Metals	Excess Cancer Risk (ECR)						Desc.
	Adult			Children			
	Min	Max	Mean	Min	Max	Mean	
Cd	$1x10^{-4}$	$2x10^{-3}$	$5x10^{-4}$	$1x10^{-4}$	$3x10^{-3}$	$7x10^{-4}$	UC
CrVI	$3x10^{-6}$	$6x10^{-5}$	$2x10^{-5}$	$4x10^{-6}$	$9x10^{-5}$	$2x10^{-5}$	AC

Description : ECR ≥ 10-4 (Unacceptable), ECR < 10-4 (Acceptable)
*Note : CSF Cd 15 mg/kg/day and CrVI 0.5 mg/kg/day
Source : Primary Data, 2024

Based on Table 4, the carcinogenic intake values in adult and child respondents with real-time exposure duration to heavy metals Cd and CrVI still meet the standard or do not exceed the Slope Factor (SF) reference dose.

3.2.4. Dose Response Analysis

The dose-response analysis done by finding the SF value of the risk agent that is the focus of the EHRA. Slope factor (SF) values based on US-EPA (1998) were obtained for Cd (15mg/kg/day) and CrVI (0.5mg/kg/day). The Excess Cancer Risk (ECR) values of these ingestion exposure risk agents were then used to determine the magnitude of the public health risk.

3.2.5. Risk Level Characteristics

Risk characterization is expressed as ECR for carcinogenic effects. The level of carcinogenic risk is expressed as a unitless exponent number. It is considered safe if the ECR value is ≤ 1/10,000. The risk level is said to be unsafe if the ECR value is > E-4 (10-4) or expressed as > 1/10,000 (Kemenkes RI, 2012).

Based on Table 5, it is known that the value of the level of carcinogenic risk or ECR of heavy metal Cd in adult respondents is the highest for the duration of real-time exposure, namely $2x10^{-3}$, which means that there are 2 cases in 1,000 people who can develop into cancer cases or there are two people at risk of developing cancer in a population of 1,000 people, while in children the highest for the duration of realtime exposure is $3x10^{-3}$, which means that there are 3 cases in 1,000 people who can develop into cancer cases or there are three people at risk of developing cancer in a population of 1,000 people. The risk level is considered unacceptable or unsafe when the ECR (Excess Cancer Risk) is greater than E-4 (10-4) or represented as ECR > 1/10,000. However, the real-time exposure duration to heavy metal CrVI is still considered acceptable or safe because the ECR value is less than or equal to E-4 (10-4) or expressed as ECR < 1/10,000.

3.2.6. Risk Level Category

The risk level of Cd and CrVI in the ingestion/oral exposure pathway is determined by the ECR value for children and adults. The results of the calculation of the ECR value of Cd exposure with an ECR value> E-4 mean that the contaminant has a carcinogenic risk on the ingestion/oral route. Adult respondents were 7 (82.5%) in the unsafe category, while in children, there were eight respondents (80%) in the unsafe category. CrVI exposure with an ECR value > E-4 means that the contaminant does not have a carcinogenic risk by the ingestion/oral route (Table 6).

3.2.7. Risk Management

The determination of safe limits of heavy metal concentrations in drinking water sources of carcinogenic exposure is presented in Table 7.

Based on Table 7, the unsafe heavy metal concentrations in adult and child respondents are Cd and CrVI. The safe limit for carcinogenic risk in adult respondents is $2x10^{-4}$ mg/L, and in children, Cd is $9x10^{-5}$ mg/L. The safe limit in adult respondents is $5x10^{-3}$ mg/L, and in children, CrVI is $3x10^{-3}$ mg/L.

The determination of the safe consumption amount at the drinking water source of carcinogenic exposure is presented in the following Table 8.

Based on Table 8, the unsafe heavy metal concentrations in adult and child respondents are Cd and CrVI. The determination of the safe amount of consumption in drinking water sources for 70 years in adult respondents is Cd is 0.04 mg/L, and CrVI is 1.2 mg/L, while safe consumption in child respondents is Cd 0.01 mg/L and CrVI is 0.68 mg/L.

Table 6. Distribution of Respondents by Realtime Carcinogenic Risk Level Category in Drinking Water Sources of Baruga and Tukamasea Villagers (N=40)

Age Group	Big Risk	Excess Cancer Risk (ECR)	
		Cd	CrVI
Children	$>E^{-4}$	**8 (20%)**	0 (0%)
	$\leq E^{-4}$	32 (80%)	40 (100%)
Adult	$>E^{-4}$	**7 (17,5%)**	0 (0%)
	$\leq E^{-4}$	33 (82,5%)	40 (100%)

Souce: Primary Data, 2024

Table 7. Determination of safe limits of heavy metal concentrations of Cd and CrVI in adult and child respondents in Baruga and Tukamasea villages

Category	HM	K	SF	Wb (kg)	tavg	IR	fE	Dt	safe limit (mg/L)
Adult	Cd	10^{-4}	15	55	25550	2,2	365	70	2×10^{-4}
	CrVI	10^{-4}	0.5	55	25550	2,2	365	70	5×10^{-3}
Children	Cd	10^{-4}	15	17	25550	1,3	365	70	9×10^{-5}
	CrVI	10^{-4}	0.5	17	25550	1,3	365	70	3×10^{-3}

Source: Primary Data, 2024

Table 8. Determination of Safe Consumption Amounts of Heavy Metal Concentrations in Drinking Water Sources in Communities in Baruga Village and Tukamasea Village

Category	HM	K	SF	Wb (kg)	tavg	CW	fE	Dt	safe consumption (mg/L)
Adult	Cd	10^{-4}	15	55	25550	0,01	365	70	0,04
	CrVI	10^{-4}	0.5	55	25550	0.005	365	70	1.2
Children	Cd	10^{-4}	15	17	25550	0,01	365	70	0,01
	CrVI	10^{-4}	0.5	17	25550	0.005	365	70	0,68

Source: Primary Data, 2024

4. Discussion

4.1. Cadmium (Cd) and Chromium (Cr VI) Concentrations

The concentration of cadmium (Cd) and chromium (Cr) VI 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 people living in Tukamasea Village and Baruga Village. Using random sampling techniques, measurements were carried out at 40 points consisting of 20 wells in Tukamasea Village and 20 wells in Baruga Village.

In Figure 7, it is explained that the industrial emissions of the cement factory will produce several pollutants such as Cd and CrVI, which can pollute the surrounding area, and the pollutant material will enter the well water of residents around the cement factory, then will be consumed by residents continuously which can cause health problems to the risk of cancer.

Based on the analysis results, the average measurement results of heavy metals Cd and Cr at each sample point do not exceed the threshold value. The results of laboratory examinations of cadmium (Cd) concentrations vary at each point, the lowest being 0.001 mg/L and the highest content being 0.005 mg/L. Based on the results of laboratory examinations of 40 water samples, nine exceeded the maximum level allowed according to the Regulation of the Minister of Health of the Republic of Indonesia, Number 492 of 2010, which is 0.003 mg/L. The heavy metal chromium (Cr) VI content concentration was also found to vary at each well water sample point from 0.005 mg/L to 0.010 mg/L. The results of the examination of heavy metal chromium (Cr) VI content found 8 out of 40 sample points containing CrVI concentrations that exceed the maximum level allowed according to the Regulation of the Minister of Health of the Republic of Indonesia Number 492 of 2010, which is 0.05 mg/L.

The high concentrations of cadmium (Cd) and chromium (CrVI) in the well water samples in the Baruga and Tukamasea villages are because they are the two villages closest to PT Semen Bosowa. The highest concentrations of cadmium (Cd) and chromium (CrVI) were found in the sample points closest to PT Semen Bosowa because some activities in the cement industry produce polluting emissions into the air that are eventually carried away and contaminate the wells of the surrounding community. Other factors affecting the high concentrations of cadmium (Cd) and chromium (CrVI) in the well water are the condition of the wells that are left open or uncovered and the wind direction that leads to certain points that cause the concentration of cadmium (Cd) and chromium (CrVI) at that point to be higher than other points.

Pollutants emitted by industry will experience dispersion in the atmosphere, which is influenced by atmospheric dynamics such as wind speed and direction, turbulence, air temperature and atmospheric stability [24]. Based on the wind rose in (Figure 4), it shows that the dominant wind direction blows west and southeast. This results in the spread of Cd and CrVI emissions. The further southeast you go, the more the concentration increases. So, wind direction is one factor contributing to the high concentration of Cd and CrVI at certain points.

Research conducted by [25] Five heavy metals—cadmium, chromium, lead, manganese, and zinc—has been evaluated in 101 water samples that were gathered from 33 different places. The apparatus made use of AAS and ICPMS. Descriptive statistics using data has been SPSS-analyzed. The collected data and the WHO Standard for Drinking Water Quality were compared. The concentration of zinc was 0.020 mg/l, manganese was 1.80 mg/l, and cadmium was 0.002 mg/l. Furthermore, the levels of lead and chromium in all the water samples were below the detection limit. The concentrations of all heavy metals were lower than the upper limit that was permitted.

Heavy metals are typically harmful to organisms, while certain ones are essential in minimal quantities. Heavymetals can be transmitted to different parts of the human body through numerous means, such as air, food, and water that are contaminated with these metals. Additionally, certain of these metals has the ability to accumulate in the body. If this condition persists, it has the potential to escalate to levels that pose a threat to human well-being [26]. Heavy metals are generally carried through rivers and wastewater. In lakes and rivers, heavy metals are discharged from the final effluent of sewage treatment plants and are common pollutants in effluents, especially if there are industrial waste inputs. Heavy metals tend to accumulate in lakes, streams, and coastal areas, particularly where industrial pollution are directly released into the water system [27].

Very small levels of heavy metal chromium are found in bodies of water due to natural processes including weathering rocks and land runoff. However, human activities including industrial processes, home garbage, and other activities involving waste entering the waterways can cause heavy metal chromium levels to rise significantly [28]. The quality of the water will be impacted by the introduction of contaminants. There is no text provided. Chromium, a metal that might be potentially dangerous, can be found in water and groundwater. It can originate from both natural occurrences and human activities. Geogenic processes and microbial interaction with mafic and ultrabasic rocks result in the release of hexavalent chromium (Cr (VI)) into the natural environment through chromite oxidation. Furthermore, a number of industrial uses of Cr (VI) in the production of energy, the manufacture of metals and chemicals, and the management of waste and wastewater are strongly linked to Cr (VI) contamination [29].

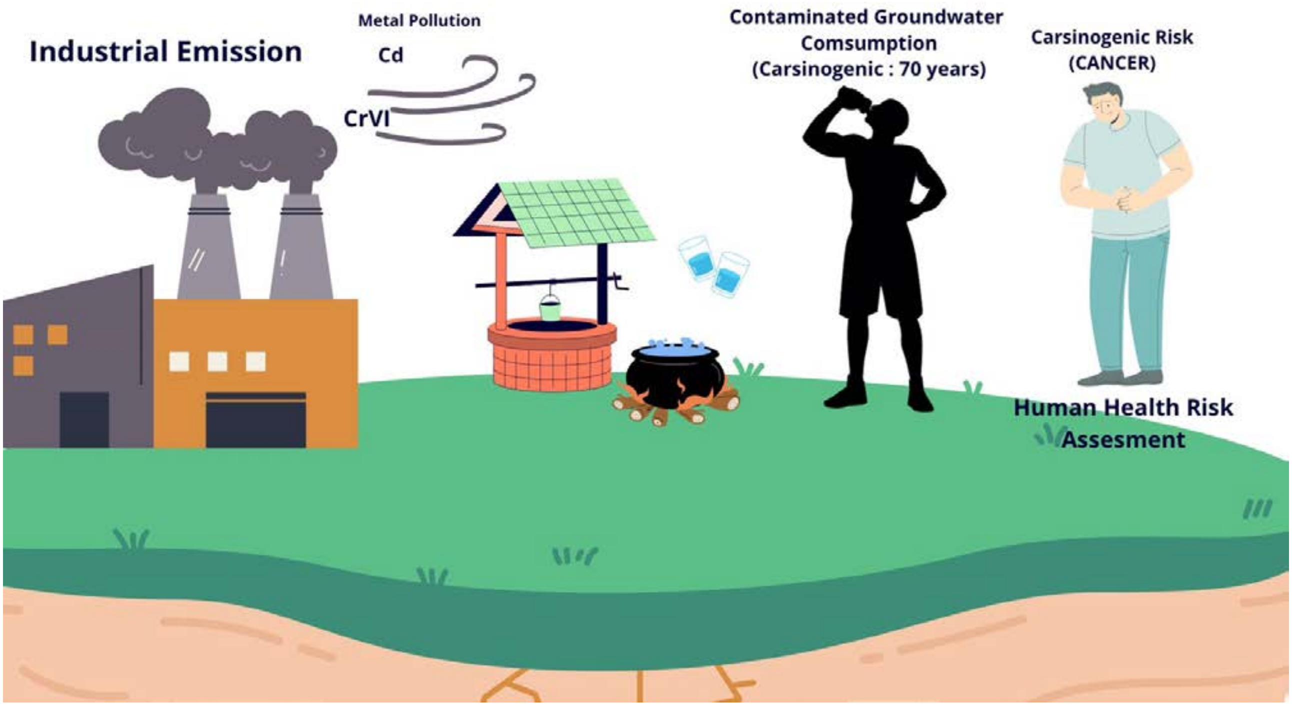


Figure 7. Illustration of entering the exposure source into the body

4.2. Health Risk

Heavy metals are well recognized as significant and prevalent contaminants in groundwater due to their harmful effects on living organisms, long-lasting nature, and ability to accumulate in biological systems [30]. These pollutants can be produced by both natural and man-made processes, such as the weathering of minerals, mining, agricultural production, industrial manufacture, and the buildup of household trash [31]. While certain heavy metals are necessary for human physiological processes in small amounts, excessive consumption can pose a risk to human health [32].

From the research results, data was found on diseases often experienced by people in Baruga Village and Tukamasea Village throughout 2023, namely, headaches, fever, itching (allergies), stomach ulcers, hypertension, coughs and diarrhea. Some of the diseases that often occur in local communities are environmental-based diseases, most likely caused by heavy metal contamination, including coughing, itching (allergies) and diarrhea. Of several respondents who were investigated regarding the diseases they often suffered from, they answered that they often experienced itching on their skin and diarrhea. Cadmium absorbed through digestion can cause nausea, vomiting, diarrhea, stomach ache, and tenesmus (whooping).

Cadmium is a metal that will settle over a certain time if it enters the body. The outcome will result in harm not only to the skeletal structure and renal organs, but also to the reproductive glands, cardiovascular organ, hepatic organ, cerebral organ, and circulatory system [33]. Cadmium can also cause psychological disorders because of its similar chemical properties to zinc; especially cadmium can replace zinc in several enzymes [34].

The presence of Cr in industrial waste has the potential to become a pollutant because of its persistent nature in the environment [35]. The entry of Cr into the food chain has the potential to cause health problems. Large accumulations of Cr in the body can affect liver health, respiratory tract disorders and kidney failure [36].

4.3. Risk Management

After conducting an environmental health risk analysis and obtaining Cd exposure with an ECR value > E-4, the contaminant has a carcinogenic risk in the ingestion/oral route. However, for CrVI exposure, the ECR value shows it is still safe, or the contaminant has no risk. Still, it does not rule out the possibility that the source exposure will become wider and greater, so follow-up action is needed. In the field of risk management, a method is used to manage risks associated with the heavy metals Cd and CrVI. This strategy involves establishing safe thresholds for the duration, time, and frequency of exposure to these risk agents [37]. Risk management is a follow-up action that must be carried out if the results of risk characterization show an unsafe or unacceptable level of risk [38].

Risk management by controlling the intake rate can also be done by reducing the amount of ground air consumed while maintaining other factors such as heavy metal concentration, body weight, and frequency of exposure, as in conditions when this research was carried out. In the application of risk management, which is a decision-making process that can be carried out for control, it will involve and consider many other factors, such as social and economic factors, as well as relevant techniques, so that risk management can be achieved well, risk management choices must be communicated with the parties involved. Interested parties in the area of risk management will be implemented.

5. Conclusions

Concentrations of exposure to the heavy metals Cd and CrVI at 40 well water sample points in two, namely Baruga Village and Tukamasea Village, Cd concentrations ranged from <0.001 mg/L – 0.005 mg/L and CrVI concentrations ranged from <0.005 mg/L – 0.010 mg/L, The concentration mentioned does not meet the quality requirement set by Minister of Health Regulation 416/Menkes/Per/IX/1990 for clean water and Minister of Health Regulation 492/Menkes/Per/IV/2010 for drinking water.

The carcinogenic risk level or Excess Cancer Risk (ECR) value based on real-time exposure to the heavy metal Cd in the children's age group was found to be 8 (40%) respondents who had an ECR value > E-4. In the adult age group, 7 (35%) respondents had an ECR value > E-4, which means the contaminant has a carcinogenic risk in the ingestion/oral route. Meanwhile, regarding CrVI metal exposure respondents had an ECR value ≤ E-4, which means it is still safe or not at risk for children and adults.

Risk management has several variables that are measured to reduce the risk of heavy metal concentrations of Cd and CrVI in drinking water sources for the people of Baruga Village and Tukamasea Village, namely, Determining Safe Concentration Limits and determining safe consumption amounts. Several of these variables can be controlled in risk management to avoid the resulting health effects. Risk management is conducted to protect the safety of persons or communities who may be exposed to hazardous agents, to prevent health issues caused by these agents.

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