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Health risk analysis of nitrite, nitrate, and heavy metal pollution in groundwater near landfill area: A case study of the Sumur Batu village in Bekasi, Indonesia

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Abstract. Previous studies state that improper landfill or waste management is one of the main causes of nitrite, nitrate, and heavy metal contamination in groundwater. In Bekasi, Indonesia, 70% of the population depends on groundwater for daily use, including the residents of Sumur Batu. The village of Sumur Batu is located adjacent to two landfills, namely, the Bantar Gebang landfill, which is the largest landfill in Indonesia, and the Sumur Batu landfill. This research analyzed the health risk of drinking groundwater that may have been contaminated by nitrite, nitrate, and heavy metals. Data processing was performed separately for different age groups: infants, children, and adults. The results showed that there is a risk of NO_2 exposure in all age groups when groundwater is used as a source of drinking water in Sumur Batu. Because the region is directly bordered by a landfill area and the community is highly dependent on groundwater, as long as access to water services is not guaranteed, the quality of groundwater in this area needs to be monitored.

1. Introduction

Water is a crucial basic human need, and one-third of the world's population depends on groundwater to meet their daily needs [1]. Previous studies state that improper landfill or waste management is one of the main causes of nitrite, nitrate, and heavy metal contamination in groundwater [2][3]. The city of Bekasi has relatively high population growth, which is causing some people to face difficulties in accessing an adequate supply of safe water. Only 26.8% of Bekasi City's water needs are met by the government [4]. Sumur Batu is one of the urban villages in Bekasi City that is very dependent on groundwater because it hasn't yet obtained guaranteed water access from the government. This village is directly adjacent to two landfills, namely, the Bantar Gebang landfill and Sumur Batu landfill.

The Bantar Gebang landfill is the largest landfill in Indonesia, receiving up to 7,000 tons of garbage from the city of Jakarta per day. This 110.3 Ha landfill has been operating since 1989 with a sanitary landfill treatment system [5]. However, the waste at Bantar Gebang Landfill is not professionally handled [6], and its leakage has caused water pollution and air pollution [7]. The Sumur Batu landfill, which has an area of 21 ha, is located in Sumur Batu village and receives 700–900 tons of garbage per day from 12 sub-districts of Bekasi. The waste management system at the Sumur Batu landfill involves open dumping, which has a great potential to cause various types of pollution.

Although many households in Sumur Batu are dependent on groundwater, its quality is declining. The groundwater in the area around the Bantar Gebang landfill is likely to have been polluted [8]. This is also evidenced by several previous studies, including research which states that the average contents of Cr, Zn, Fe, Mn, and Hg in all wells sampled around the Bantar Gebang sub-district of Bekasi are 2.12 mg/l, 7.34 mg/l, 0.86 mg/l, and 13.31 mg/l, respectively. Those values are above the quality threshold for class 1 water (i.e., clean water used for drinking) defined by Government Regulation No. 82, enacted in 2001[9]. Using the STORET system from the US Environmental Protection Agency (US EPA), Bethy (2011) shows that the well in the Bantar Gebang sub-district has poor water quality and is affected by the Bantar Gebang landfill [10].
Leachate produced by solid waste contains many organic and inorganic compounds. Based on Irhamni's (2017) research, the leachate from landfill can contain heavy metals, such as mercury (Hg), copper (Cu), iron (Fe), cadmium (Cd), cobalt (Co), zinc (Zn), nickel (Ni), chromium (Cr), and lead (Pb). Additionally, the decomposition of organic matter by bacteria will lead to high nitrate and nitrite content in the waters [11]. The entry of leachate into groundwater and its distribution is expected to occur through the process of osmosis, capillarity mechanisms and electrokinetic processes [12].
In southwest Nigeria, it was reported that the presence of heavy metals in groundwater can significantly increase the health risks of cancer and non-cancer [2]. While, a high content of nitrates in drinking water is associated with methemoglobinemia, which is a great risk for infants under 6 months [13]. Additionally, a study in India shows that the location of municipal waste disposal broadly contaminated Chandigarh's groundwater. The average risk quotient (RQ) for As, Co, Cd, Cu, Ni, Pb, and Zn (but not for Cr) is >1. Therefore, consumption of Chandigarh groundwater has the potential to cause non-carcinogenic health impacts on living things [3].

2. Materials and method

2.1 Study area

The study was located in Sumur Batu, Bantar Gebang, Bekasi. Sumur Batu has an area of 5.7 km^2 and a population of 17,002 people. Residents mainly obtain groundwater from a borehole. The study location was selected used a purposive sampling method based on several criteria: high use of groundwater as a source of drinking water, a lack of piped water connection, high poverty rate, high population density, and proximity to landfills. A total of 24 groundwater samples were taken based on random sampling in Sumur Batu, a map of the sample distribution at the study locations is shown in Figure 1.

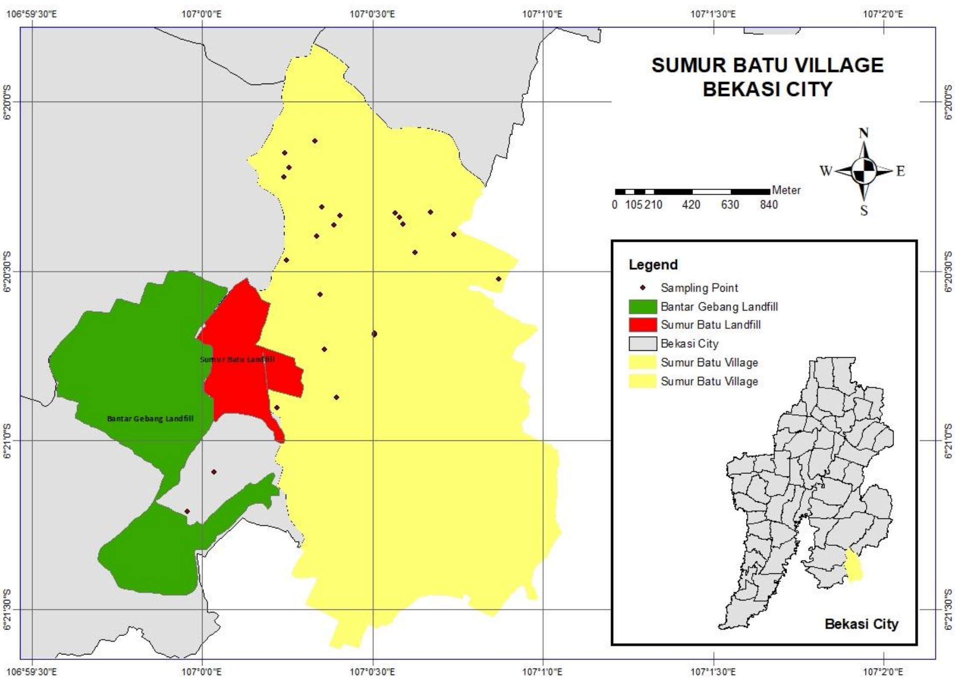

Figure 1. Study site area (Sumur Batu) and sampling point distribution

2.2 Sampling and analysis
Water sampling from wells in households was carried out at 24 sample points in the rainy season, from 2–14 March 2020. Groundwater samples were collected from boreholes with a depth of 10–15 m below the ground surface. The high-density polyethylene (HDPE) bottles, which were used as a water sample container, were washed three times with the sample before the sample was collected. Each sample was put into two bottles, one bottle for the nitrite and nitrate test and another for the heavy metal test. The pH and total dissolved solids (TDS) were measured in the field using a multiparameter (HANNA-HI9828) that was calibrated beforehand. Then, samples were preserved based on SNI 06-6989.16-2004. Each nitrite-nitrate sample was acidified in situ with 2 M H_2SO_4 until a pH of <2 was achieved. Heavy metal samples were also acidified with 2 M HNO_3 until a pH of <2 was achieved in order to dissolve all the heavy metals and prevent crystallization or precipitation and adsorption of trace metals to the container surfaces before analysis. All water samples were kept at 4°C in a sealed cooler and then transported to the laboratory for analysis of the concentrations of nitrite and nitrate by a spectrophotometer and the concentrations of Cr, Zn, Fe, Mn, Hg, and Cd by inductively coupled plasma mass spectrometry (ICP-MS) and atomic absorption spectrophotometry (AAS).

2.3 Questionnaires
This study is focused on households who consume shallow groundwater in Sumur Batu. Based on the Slovin method of considering the population number, the minimum number of samples (in this case, respondents) who can represent Sumur Batu is 391 people. In this study, 143 households (597 residents) were randomly chosen. This amount is consideread to represent the population of the Sumur Batu. Face-to-face interviews using a questionnaire were carried out with those households in the same period as water sampling, 2–14 March 2020. The age range was 0–90 years. The questionnaire asked for general information about the participants and their groundwater consumption behavior, such as the intake rate, frequency, and quantity of consumption.

2.4 Health risk assessment
Health risk assessment is a method for calculating the carcinogenic and non-carcinogenic risks to human beings after chemical exposure. The ingestion of contaminated groundwater can adversely affect human health through a variety of methods of exposure, including direct ingestion, dermal contact, and washing [14]. However, this study only considers the effects of groundwater consumption on human health as an exposure pathway. The absorption of potential toxins through drinking water can be expressed by chronic daily intake (CDI), which is calculated as follows [14]:

$$CDI = C \times IR \times EF \times ED / BW \times AT, \quad (1)$$

where CDI is the ingestion dose from drinking water (mg/kg/day) and C is the estimated concentration of pollutants in groundwater samples (mg/l). In this research, BW data were obtained from a article about the median body weights for different age groups of the Indonesian population [15]. The parameter values used to calculate CDI can be seen in Table 1.

Table 1. Calculation of parameters included in the CDI for health risk assessment

Parameter	Meaning	Value			Unit
		Adult	Children	Infant	
IR	Amount of drinking water	2,09[a]	1[b]	0.3[c]	L/day
EF	Exposure frequency	350[b]	350[b]	350[b]	days/year
ED	Exposure duration	30[b]	12[d]	1[d]	Year
BW	Body weight		According to age[e]		Kg
AT	Exposure time (lifetime)	23,360[d]	4,380[d]	365[d]	Days

[a] These data come from questionnaires.
[b] These data come from [14].
[c] These data come from [16].
[d] These data come from [17].
[e] These data come from [15].

The ingested amount of risk agent, which is calculated using Eq. 1, can be used to estimate the ingested HQ (hazard quotient). The HQ describes the risk of reporting oral non-carcinogens due to the ingestion of water, which is expressed as follows:

$$HQ = CDI / RfD \quad (2)$$

If HQ < 1, there is no apparent non-carcinogenic risk or an acceptable level of risk. If HQ > 1, there is an unacceptable risk of adverse non-carcinogenic effects [14]. RfD refers to the reference dose for ingestion (mg/kg.day), and it can be obtained from the Integrated Risk Information System (IRIS) database [14]. The RfD values used in this study are presented in Table 2.

Table 2. Toxicity responses **(**dose response**)** to oral exposure

Parameter	RfD (mg/kg.day)
NO_2	0.1
NO_3	1.6
Cr	0.003
Zn	0.3
Fe	0.7
Mn	0.14
Hg	0.0001
Cd	0.0005

3. Result and discussion

3.1 General characteristics of respondents

The respondents consisted of children to adults of various ages, ranging from 0–90 years. Age affects the body's resistance to disease and exposure to poisons/pollutants. In this study, the average age of the respondents was 29. However, those at the minimum and maximum ages—0 years and 90 years, respectively—are vulnerable and at risk of exposure to poisons.

The respondents were divided into three age groups: adults, children, and infants. The largest group is the adult population aged 17–90 years, with a percentage of 68.51%. The proportion of respondents aged 3–16 years was 24.62%, while the number of infants aged 0–2 years was 6.87%. The

3.2 Quality of groundwater samples

In total, 24 groundwater samples from 24 wells of Sumur Batu village residents were checked in situ to determine their pH and TDS values. Then, nitrite (NO_2), nitrate (NO_3), and heavy metal measurement was performed in the laboratory using a spectrophotometer, ICP-MS, and AAS technology. The test results for groundwater sample parameters in this study are presented in Table 3.

Table 3. Water quality test results

Sample	pH	TDS (ppm)	NO_2-N (ppm)	NO_3-N (ppm)	Cr (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Hg (ppm)	Cd (ppm)
PP No. 82/2001	6–9	1000	0.06	10	0.05	0.05	0.3	0.1	0.001	0.01
1	4.8	143	0.61	2.94	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
2	5.7	152	0.00	2.94	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
3	4.7	104	0.61	2.53	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
4	5.7	165	0.91	0.86	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
5	5.5	78	0.30	1.63	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
6	5.1	144	1.22	1.85	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
7	5.8	90	0.30	1.26	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
8	5.7	146	0.61	1.90	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
9	7.1	151	0.30	0.27	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001

10	6.2	149	2.13	2.78	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
11	5.6	142	0.61	2.44	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
12	5.1	123	0.30	3.21	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
13	5.9	193	0.91	1.74	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
14	6.0	117	0.61	0.63	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
15	6.1	413	0.61	2.48	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
16	5.3	138	0.91	2.60	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
17	5.0	97	0.61	1.47	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
18	4.4	83	0.61	1.63	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
19	5.6	288	0.91	6.01	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
20	5.2	160	0.91	4.27	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
21	5.4	83	0.30	2.57	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
22	5.8	112	0.30	1.49	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
23	5.7	144	0.30	2.33	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
24	6.3	141	0.30	1.15	<0.01	<0.01	<0.02	<0.01	<0.0006	<0.001
Mean	5.6	148.2	0.6	2.2						
Std Dev	0.6	71.2	0.4	1.2						
Limit of Detection					**<0.01**	**<0.01**	**<0.02**	**<0.01**	**<0.0006**	**<0.001**

Based on Table 3, the 24 samples have varying pH values but tend to be acidic. Based on the Indonesian Government Regulation No. 82, enacted in 2001, only 4 of the 24 groundwater samples met the pH requirements for raw drinking water. Based on data from the Bekasi City government, the land around the Bantar Gebang village is alluvial. Alluvial soils have pH conditions that tend to be acidic, which can affect the pH of groundwater. Water with a low pH (below 6) can cause corrosion of metals (water pipes), dissolving the elements of Pb, Cu, and even Cd. Water acidity levels can trigger health problems, such as flu, allergies, and skin disorders, and if corrosion occurs, they can cause poisoning [18]. However, the TDS value of all water samples is considered to be safe according to Indonesian Government Regulation No. 82.

Of the 24 well water samples, only 1 has an NO_2-N content that meets the quality standard for drinking water. For NO_3-N content, all samples meet the quality standard. On average, the NO_2-N content is lower than the NO_3-N content. This shows that the process of nitrifying microorganisms in the soil is going well. NO_2 is usually present in groundwater at very low concentrations because it is very easily converted into NO_3 [19]. But even in low concentrations, the presence of nitrates in a water environment must be monitored because of their high toxicity. The Cr, Zn, Fe, Mn, Hg, and Cd contents in the 24 groundwater samples were very low and below the detection limit. This might be due to the groundwater flow from the landfill area, which does not lead to the Sumur Batu sub-district. According to Syamsu Rosid et al. (2011), who used the self-potential method to conduct their research, the subsurface groundwater flows in the Bantar Gebang landfill area are oriented from south to north [12]. However, in this study, the location of the study was to the east of the landfill area.

3.3 Health risk assessment

Laboratory test results for 24 samples showed heavy metal values below the detection limit. Based on the US EPA, when pollutant values are below the detection limit, the health risks can be calculated using half of the detection limit. The detection limit is the lowest concentration (not 0) below the level that can be measured with acceptable precision. At the detection limit, analytes are proven to exist, but the reported concentrations are estimates [20]. In this study, the non-cancer risk of drinking water was calculated in three age groups for real time, real time + 5, real time + 10, real time + 15, and lifetime. The real time risk is the risk after a long period of exposure before this research. The real time risk + 5 refers to the risk 5 years after the study was conducted, and so on. Lifetime risk refers to the risk if the resident continuously consumes polluted groundwater.

Table 4. Risk analysis of groundwater contaminated with heavy metals as a source of drinking water

Parameter		Percentage of respondents with HQ > 1 (%)					
		Real time	Real time + 5	Real time + 10	Real time + 15	Lifetime	Risk
Infant (n = 41)	**NO_2**	19.5	0	0	0	19.5	**At risk**
	NO_3	0	0	0	0	0	No risk
	Cr	0	0	0	0	0	No risk
	Zn	0	0	0	0	0	No risk
	Fe	0	0	0	0	0	No risk
	Mn	0	0	0	0	0	No risk
	Hg	0	0	0	0	0	No risk
	Cd	0	0	0	0	0	No risk
Child (n = 147)	**NO_2**	33.3	0	0	0	33.3	**At risk**
	NO_3	0	0	0	0	0	No risk
	Cr	0	0	0	0	0	No risk
	Zn	0	0	0	0	0	No risk
	Fe	0	0	0	0	0	No risk
	Mn	0	0	0	0	0	No risk
	Hg	0	0	0	0	0	No risk
	Cd	0	0	0	0	0	No risk
Adult (n = 409)	**NO_2**	0.2	0.2	1.2	1.7	0	**At risk**
	NO_3	0	0	0	0	0	No risk
	Cr	0	0	0	0	0	No risk
	Zn	0	0	0	0	0	No risk
	Fe	0	0	0	0	0	No risk
	Mn	0	0	0	0	0	No risk
	Hg	0	0	0	0	0	No risk
	Cd	0	0	0	0	0	No risk

Based on the estimated health risks calculated in Table 4, exposure to NO_3 and Cr, Zn, Fe, Mn, Hg, and Cd in groundwater samples incur no or limited risk in all age groups until 15 years after this study. However, there are risks associated with NO_2 in all age groups. As many as 19.5% of the infant age group are at risk of being affected by NO_2 through real time and lifetime exposure. In the child age group, as many as 33.3% of respondents are at risk of real time and lifetime NO_2 exposure. In the adult age group, there is a risk of NO_2 exposure at the real time, real time + 5, real time + 10, and real time + 15 time points. As many as 0.2% of the adult age group have a non-cancer health risk associated with NO_2 due to oral exposure in real time and the next 5 years; 1.2% has a risk of NO_2 exposure in the next 10 years; and 1.7% are at risk of NO_2 exposure in the next 15 years.

High nitrate exposure incurs a great risk, especially in infants and pregnant women [13]. In the bloodstream, nitrites oxidize iron in hemoglobin molecules and produce methemoglobin. This condition is called methemoglobinemia. Iron that has been oxidized can no longer bind oxygen, and the ability of blood cells to carry oxygen to the body is reduced, inhibiting the growth of organs and even leads to death. Also, years of low nitrate exposure can affect adult health by causing gastric cancer, respiratory disorders, headaches and fatigue, thyroid gland hypertrophy, and multiple sclerosis (an autoimmune disorder that attacks the central nervous system) [21].

Because Sumur Batu is directly bordered by the landfill area and the community is highly dependent on groundwater, the quality of groundwater in this area needs to be monitored. Especially among vulnerable infants, the consumption of groundwater for drinking needs to be limited. Breastfeeding until the age of two years is highly recommended, and the need for water for formula milk or complementary foods can be met using safer water like bottled water.

4. Conclusion

The contents of Cr, Zn, Fe, Mn, Hg, and Cd are below the limit of detection in all groundwater samples. This may be due to the direction of groundwater flow from the landfill, which does not lead to Sumur Batu. The results of a health risk analysis of NO_3 and heavy metals in groundwater in the Sumur Batu sub-district indicate that using this groundwater as a source of drinking water does not cause significant health effects in all age groups until 15 years later. However, there are risks associated with NO_2 in all age groups. Because the region is directly bordered by the landfill area and is highly dependent on groundwater, the quality of groundwater in this area needs to be monitored. Especially among vulnerable infants, the intake of groundwater needs to be limited.

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