PAN
POLSKA AKADEMIA NAUK
JOURNAL OF WATER AND LAND DEVELOPMENT
e-ISSN 2083-4535
ITP-PIB
Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2024.149113
2024, No. 60 (I–III): 112–121

The microbial and chemical risk analysis of drinking water in a small island, Spermonde Archipelago

Agus B. Birawida*[1)], Anwar Daud[1)], Erniwati Ibrahim[1)], Healthy Hidayanty[2)], Nurlia Sila[1)], Maming Maming[3)], Muhammad Nur[4)], Ain Khaer[5)], Andi I. Arundhana[6)], Arsunan Arsin[7)]

[1)] Hasanuddin University, Department of Environmental Health, Jl. Perintis Kemerdekaan Km 10, Makassar, South Sulawesi, 90245, Indonesia
[2)] Hasanuddin University, Department of Nutrition, Jl. Perintis Kemerdekaan Km 10, Makassar, South Sulawesi, 90245, Indonesia
[3)] Hasanuddin University, Department of Chemistry, Jl. Perintis Kemerdekaan Km 10, Makassar, South Sulawesi, 90245, Indonesia
[4)] Hasanuddin University, Department of Mathematics, Jl. Perintis Kemerdekaan Km 10, Makassar, South Sulawesi, 90245, Indonesia
[5)] Health Polytechnic, Department of Environmental Health, Jl.Wijaya Kusuma 1 No.2, Makasssar, South Sulawesi, 90222, Indonesia
[6)] The University of Sidney, Faculty of Medicine and Health, Science Rd, Camperdown NSW 2050, Australia
[7)] Hasanuddin University, Department of Epidemiology, Jl. Perintis Kemerdekaan Km 10, Makassar, South Sulawesi, 90245, Indonesia

* Corresponding author

RECEIVED 27.06.2023 ACCEPTED 22.11.2023 AVAILABLE ONLINE 22.03.2024

Abstract: Coastal areas face greater risk in terms of health and the environment. They are the most vulnerable to impacts resulting from climate change. Coastal areas with higher population density also have more environmental problems, such as natural disasters. Environmental health risks from chemicals and microbes continue threatening people living on small islands. Therefore, this study aims to: 1) conduct a chemical risk analysis of heavy metals Pb, Cr(VI), and Ni; 2) analyse the microbial risk posed by drinking water consumed daily by people on small islands. A method used to analyse the chemical risk of heavy metals was the environment health risk assessment (EHRA), whereas to analyse the microbial risk in small islands, the quantitative microbial risk assessment (QMRA) was used. The results showed that the concentration of heavy metals in drinking water was <0.0012 mg·dm^{-3} for Pb, <0.01 mg·dm^{-3} for Cr(VI), and <0.0019 mg·dm^{-3} for Ni. The three heavy metals showed worrying results. Assessment and obtained risk quotient were less than one (RQ < 1) in all samples. Meanwhile, the microbial analysis found *Escherichia coli*, *Acinetobacter calcoaceticus*, *Enterobacter* sp., and *Citrobacter* sp., with risk characterised from low to high. Risk management is needed to control environmental health risks posed by heavy metals and the microbiological characteristics of drinking water on the small islands of the Spermonde Archipelago.

Keywords: chemical risk, environment health risk assessment microbial risk (EHRA), quantitative microbial risk assessment small island (QMRA), risk analysis, water quality

INTRODUCTION

Coastal communities exhibit various characteristics, including limited environmental awareness, disregarded environmental health, and insufficient access to clean water (Subagiyo, Wijayanti and Zakiyah, 2017). Small islands are particularly susceptible to the effects of climate change (Doorga, 2022). Moreover, coastal areas with higher population density encounter more environmental challenges, such as natural disasters (Kao, Wu and Gu, 2023). The coastal environment faces significant threats like storms and erosion, adversely impacting their physical, economic, and social systems (Bevacqua, Yu and Zhang, 2018). Small islands in disaster-prone regions are also seriously jeopardised due to climate change (Kao, Wu and Gu, 2023). Communities in the coastal areas of the islands are vulnerable to the climate crisis and tidal floods, which can submerge several villages in coastal regions. This research uses a quantitative risk analysis approach to measure exposure to environmental hazards to human health supported by risk management (EPA IRIS). Over time, climate change has severely affected native island ecosystems and jeopardised long-term freshwater supply systems (Doorga, 2022).

The availability of water resources, both in terms of quality and quantity, is a critical concern in numerous regions worldwide, with small islands facing significant challenges (Papapostolou *et al*., 2020). A study by Birawida *et al*. (2021) discovered that community behaviour ($P < 0.01$) and population density ($P < 0.01$) were the primary factors associated with vulnerability to clean water on small islands of the Spermonde Archipelago (Birawida *et al*., 2021).

Small islands face various challenges, not only related to the environment but also to health. As regards ecologically, small islands are very fragile and vulnerable. Their small size, limited land, scarce resources, geographical distribution, and isolation contribute to their vulnerability (Ersel, 2015). These problems are interconnected within the Spermonde Archipelago. Economic concerns endanger the well-being of coastal and island communities. These include basic hygiene, access to clean water, and limited food availability. Water pollution is also prevalent, with 14 out of 18 well water found to be polluted according to the water quality index (*WQI*) (Syamsir, Birawida and Faisal, 2019).

Island communities often rely on water sources which should meet specific requirements and maintain cleanliness. The quality of coastal raw water can be compromised due to high salt concentration, pollution from rainfall-induced flooding during the wet season, and water scarcity, particularly during the dry season (Heston and Alvira, 2021). Consequently, islands become vulnerable to diseases and fatalities resulting from poor sanitation and health (Ersel, 2015).

Besides heavy metals, coastal water is also prone to bacterial contamination. This contamination is often caused by unhealthy practices of the local community, such as building houses directly on the sea without proper septic tanks and discharge of waste directly into the sea (Dewi, 2019). The study by Jiang *et al*. (2019) found that out of 22 freshwater samples, 86% tested positive for *Legionella* and 82% for *Escherichia-Shigella*. *Enterococcus faecalis* was detected in over 68% of rainfall samples and 60% of coastal waters (Jiang *et al*., 2020).

According to study by Amatobi and Agunwamba (2022), 62% of water sources in developing countries are contaminated with pathogenic bacteria. The average concentration of *Escherichia coli* bacteria is 0.325 CFU, with a corresponding disease risk level of 0.065. *Salmonella* spp. has an average concentration of 0.227 CFU and a disease risk level of 0.045. *Shigella* spp. has an average concentration of 0.240 CFU and a disease risk level of 0.031. *Campylobacter* has an average concentration of 0.255 CFU and a disease risk level of 0.026. *Giardia lamblia* has an average concentration of 0.218 CFU with a disease risk level of 0.044. Lastly, *Cryptosporidium parvum* has an average concentration of 0.153 CFU and a disease risk level of 0.021. Based on all pathogens, the average risk of diarrhoeal disease is 0.039, with a standard deviation of 0.016 (Amatobi and Agunwamba, 2022).

Unsanitary water conditions in coastal areas contribute to a range of health problems. Islanders often experience joint pain, mild to severe hearing loss, and conditions such as barotrauma and decompression sickness, commonly affecting divers (Dewi, 2019). Moreover, bacterial infections and diseases transmitted by vectors can also occur in coastal regions. Surira *et al*. (2020) stated that individuals living in densely populated coastal areas with stagnant water and environmental conditions that support the spread of malaria are less concerned about preventing malaria, even though they reside in endemic areas where the risk of morbidity is high, especially within their home environment.

To address the significant impact of air pollution on coastal areas, it is crucial to conduct a risk analysis to determine appropriate actions. One method used for this purpose is the Environmental Health Risk Analysis (EHRA), which involves assessing the estimated level of risk resulting from exposure to various agents, including chemical and biological substances, in at-risk populations. The EHRA considers the characteristics of the agent and the population to determine the potential risks involved. The risk assessment process in the EHRA consists of four stages. The first stage is hazard identification, which involves identifying contaminants that may pose a health hazard at environmentally relevant concentrations. The next stage is the human health dose-response assessment, which examines the numerical relationship between exposure to contaminant and its effects. The following stage is the exposure assessment, which aims to determine the frequency and extent of exposure to the contaminants (Birawida, 2021).

Based on the Barrang Lompo Health Center (2022), the number of residents using drinking water facilities is 5,093. Land use on the Barrang Lompo Island consists of trading land, educational services, markets, ports, accommodation, recreation areas, and housing. Population growth on the island has been increasing every year. Therefore, the demand for land is growing. This is caused by the large number of migrant residents who need a place to live to survive. As a result, there are changes in land use that affect the spatial layout and balance.

This research focuses on microbial and heavy metal contamination in well water used by the community on the Barrang Lompo Island. In addition, this research examines environmental problems (drinking water) on the island. Several studies have been conducted regarding drinking water pollution and these have only used descriptive/quantitative methods. Novelty in research refers to the use of a quantitative method to determine the impact of drinking water on health by combining QMRA and EHRA. Research involving risk analysis in small island areas still needs to be carried out. Hence, the results of this research are beneficial for local island residents in determining their health risks related to drinking water.

A quantitative approach has been proven to explain pollution exposure from source to risk status quantitatively, proven by the EPA IRIS research. This study aims to 1) conduct a chemical risk analysis of heavy metals Pb, Cr(VI), and Ni; 2) analyse the microbial risk posed by drinking water consumed daily by people on small islands. This study hypothesises focus on the environmental health risk due to exposure to heavy metals and microbes in drinking water. The outcomes of the analysis are expected to serve as the basis for implementing measures to mitigate both microbial and chemical health risks on a large scale in the coastal estuary waters of the Makassar Spermonde Islands.

MATERIALS AND METHODS

STUDY AREA

The Barrang Lompo Island, one of the islands in the Makassar Spermonde Archipelago located in the South Sulawesi Province of Indonesia (Fig. 1), is an area characterised by dynamic water phenomena. The status of water on the Kodingareng Island changes dynamically because the island is located at the mouth of the Makassar Strait and the Java Sea. The Barrang Lompo Island has a tropical climate determined by rainy season and monsoon drought. The season is estimated to occur from June to November. The wind speed is typically higher, so it usually rains during this time. Island communities are mainly engaged in fishing. People in the islands utilise all available natural resources to meet their daily needs. Environmental conditions and people's work on the islands are interrelated because they can affect their quality of life and health.

Fig. 1. Map of the Barrang Lompo Island research area; RW 01, RW02, RW04 = hamlets; source: Google Earth

SAMPLING METHOD

Measuring equipment includes an atomic absorption spectrophotometer (SSA) for lead (Pb) and chromium (Cr) and inductively coupled plasma (ICP) for nickel (Ni). The chemical and microbiological samples were collected from three wells. The research location was in the Spermonde Islands on the Barrang Lompo Island with 6 sampling points, namely A1, A2, A3, A4, A5, and A6. The drinking water sampling method was based on the Integrated Sampling technique. Integrated Sampling involves samples taken separately and directly from a water body monitored at several places, with the same volume of 2,000 cm^3, using a sampling bottle. The water source extraction method was according to the Indonesian National Standard (SNI 6989.58:2008). Determination of heavy metals in drinking water is based on Republic of Indonesia Minister of Health Regulation No. 492 of 2010. The research obtained ethical clearance from the Faculty of Public Health, Hasanuddin University, research ethics commission with ethical clearance number: 2507/UN4.14.1/TP.01.02/2022 (Rekomendasi, 2022).

HEALTH RISK ASSESSMENT

The risk assessment process is divided into two main categories: environmental health risk assessment (EHRA) and quantitative microbial risk assessment (QMRA). This evaluation method consists of four steps and is used to determine the likelihood of infection, with a primary focus on the impact of diseases (Fig. 2).

1. The first step in the risk analysis is hazard identification, which aims to identify the chemical and biological agents that have the potential to cause health problems when the body is exposed to them.
2. In the dose-response assessment phase of the risk analysis, laboratory feeding studies or outbreak data are employed to establish a mathematical relationship (including model selection and parameter estimation) between the amounts of pathogens and the probability of infection, illness, or death among the exposed population.
3. The exposure assessment phase considers various exposure pathways, taking into account information about pathogen concentrations in microbial sources, the movement and transport of pathogens from the source to the point of exposure, and the estimation of doses based on final concentrations and the amount consumed by key populations. This assessment considers both single and multiple exposures.
4. The risk characterisation stage integrates the exposure and dose-response assessments to determine the probability of infection, illness, and/or mortality associated with the specific heavy metal or pathogen under consideration. This process involves addressing assumptions, variability, and factors of uncertainty, taking into account relevant studies such as those by Sano, Haas, and Rose (2019) and Wu *et al.* (2020).

The Environmental Health Risk Analysis by the US EPA was used to estimate the human health risk from drinking water. The equation for the oral route non-carcinogenic risk analysis is shown in:

$$ADD_{\text{intake}} = \frac{C \cdot EF \cdot ED \cdot ET}{BW \cdot AT} \qquad (1)$$

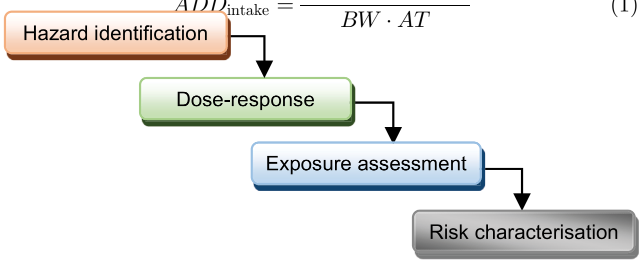

Fig. 2. Environmental risk analysis stages; source: own elaboration

$$HQ = \frac{ADD_{\text{intake}}}{RfD} \quad (2)$$

where: ADD = average daily dose of drinking water (μg·kg^{-1}·d^{-1}), C = concentration of drinking water (μg·m^{-3}), EF = frequency of drinking water exposure (350 days for residential exposure), ET = exposure of time, ED = duration of exposure, BW = body weight (kg), AT = averaging time (calculated as ED multiplied by 365 days for non-carcinogenic risk estimation), RfD = reference dose for drinking water (mg·dm^{-3}).

According to Sano, Haas, and Rose (2019), the quantitative microbial risk assessment (QMRA) plays a crucial role in connecting the levels of microbial pathogens found in the environment to identify required treatment measures. Its primary objective is to minimise risks and establish a satisfactory level of public health safety for a particular intended use or endpoint.

The dose-response (*DR*) assessment focuses on understanding the correlation between the quantity of ingested pathogens (dose) and the probability of encountering adverse outcomes, including infection, illness, or mortality. A β-Poisson dose-response model, represented by Equation (1), is employed to achieve this objective. This model, as described by Ahmed *et al.* (2020), allows for the characterisation of the dose-response relationship in the quantitative microbial risk assessment.

$$P_{\text{inf/day}} = 1 - \left(1 + \frac{d}{N_{50}}\right)\left(2^{1/\alpha} - 1\right) \quad (3)$$

where: $P_{\text{inf/day}}$ = daily probability of infection during risk characterisation, d = dose exposure, N_{50} = number of exposures per year, α = parameter of the distribution.

Equation (3) allows for estimating the likelihood of infection over a year based on the given inputs and the established dose-response relationship.

$$P_{\text{inf ann}} = 1 - \left(1 - P_{\text{inf/day}}\right)^{n} \quad (4)$$

where: $P_{\text{inf ann}}$ = probability of illness during risk characterisation, $P_{\text{inf/day}}$ = probability of infection per day, n = number of exposure days in a year.

The probability of illness (P_{ill}) can be estimated by multiplying the probability of infection per day by the number of exposure days in a year.

$$P_{ill} = P_{infann} \cdot P_{ill/inf} \quad (5)$$

where: $P_{\text{ill/inf}}$ = probability of illness per infection, and $P_{\text{inf ann}}$ is defined in Equation (4).

RESULTS AND DISCUSSION

ENVIRONMENTAL HEALTH CONDITIONS OF COASTAL AREAS

Coastal areas face greater risk in terms of health and the environment. These areas are the most vulnerable to the impacts of climate change. The coast is a transitional area of land and sea ecosystems that influence each other. Indications of climate change threatening the coast due to increasing global temperatures and rising sea levels (Ledoh, Satria and Hidayat, 2018). The temperature of the earth is warmer up to 0.6°C. Scientists predict that by the end of this century the temperature rise will increase by about 6°C (Maolani *et al.*, 2021). Coastal areas with higher population densities also have more environmental problems, such as natural disasters. Environmental health risks from chemicals and microbes continue threatening people living in small island areas. Island communities are mainly involved in fishing. People utilise all natural resources to meet their daily needs. Work environment can affect people's quality of life and health.

Environmental conditions on coasts and small islands are vulnerable to both chemical risks in the form of heavy metals and microbiological risks (Fig. 3). Chemical risks can come from industrial waste, farming, and other human activities that pollute sea around coasts and small islands. Heavy metals, such as Pb (lead), Cr(VI) (hexavalent chromium), and Ni (nickel), can accumulate in the aquatic environment. They can harm marine organisms and humans who consume these marine products. Meanwhile, microbiological risks can come from domestic waste, livestock waste and other natural factors. In this research, the results of environmental identification based on drinking water

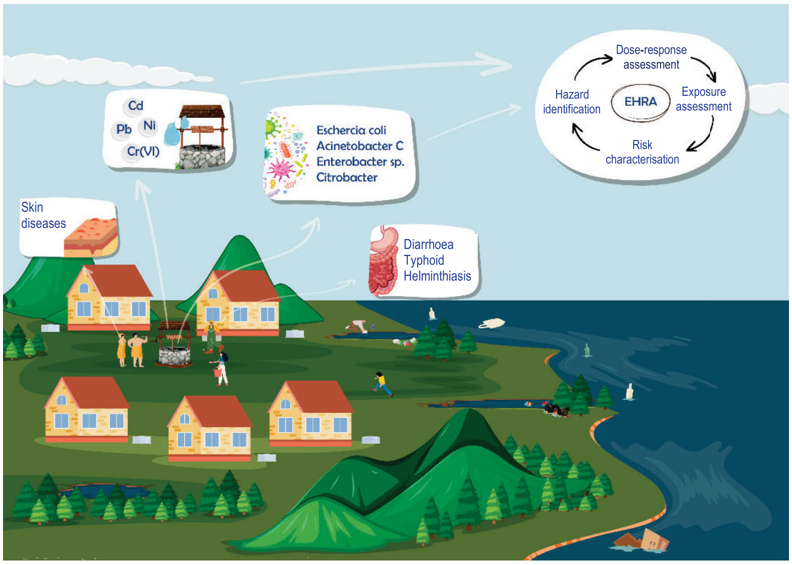

Fig. 3. Environmental risks in small island communities; source: own elaboration

show that the content of heavy metals, such as Pb, Cr(VI), and Ni, exceeds safe limits. Apart from that, microbiological elements were also found, including *Escherichia coli*, *Acinetobacter calcoaceticus*, *Enterobacter sp.*, and *Citrobacter*. They can endanger the health of humans who drink water from such sources.

PRESENCE OF HEAVY METALS IN DRINKING WATER

Communities living on small islands have limited availability of drinking water. Even though drinking water is essential to support the life of people on the island. Some of the water sources used by people on the Supermonde Island are water wells on the island, bottled water, and water purchased from the Makassar City.

Microbes and heavy metals pose a significant risk to public health when present in water sources. These contaminants can be found in various water environments, including river water, surface water, groundwater, agricultural water, and well water consumed by communities. Numerous studies have been conducted globally to assess the level of risk posed by these contaminants and their impact on public health (Tab. 1). It is crucial to understand and address this issue to ensure safety and well-being of individuals who rely on these water sources to meet their daily needs.

The most frequent exposure to heavy metals is ingestion and dermal. Additionally, the duration of exposure is also influenced by the age of adults and children. The non-carcinogenic risk resulting from the calculation of non-carcinogenic intake is divided by the reference dose (*RfD*), where the *RfD* is for Cr(VI) is $3.00 \cdot 10^{-3}$, for Pb $3.50 \cdot 10^{-3}$, and for Ni $2.00 \cdot 10^{-2}$ (US EPA, 1996) (Tab. 2). The risk of developing health problems due to heavy metal toxicity depends on not only on the duration of exposure or the respondent stay at the research location, and the amount of heavy metal concentration in groundwater, but also the rate of intake, frequency, and time of high exposure.

The results presented in Table 3 indicate that the concentrations of Pb, Cr(VI), and Ni in the six water samples were all below the WHO standards of 0.01 mg·dm^{-3} for Pb, 0.05 mg·dm^{-3} for Cr(VI), and 0.02 mg·dm^{-3} for Ni (WHO, 2008). This finding aligns with a study by Yang (2022) on Taihu Lake water in China. The study also reported acceptable levels of carcinogenic risk associated with Cr(VI), As, Pb, and Ni in drinking water. However, Yang *et al.* (2022) noted potential health risks related to ingesting Cr(VI), As, and Ni through drinking water and fish consumption.

It is crucial to regularly monitor and control the levels of toxic metals, especially Cr(VI), As, and Ni, in edible organisms to mitigate potential carcinogenic risks associated with food consumption. The risk assessment results in Table 3 demonstrate that all assessed samples and heavy metals obtained risk quotient (*RQ*) values below 1, indicating no significant risks. However, a study by Astuti *et al.* (2021) in Pangkajene found a mean concentration of Cr(VI) exceeding 0.0017 ±0.0006 mg·dm^{-3}, thus highlighting potential adverse effects on the ecological system and human health due to *RQ* values surpassing 1. Similarly, Rauf *et al.* (2021) conducted research in the Maros Regency and reported mean values of

Table 1. Risk level related to heavy metals and microbes in previous studies

Kind of sampling water	Metal or microbe	Reference level of risk	Measured concentration	*RQ*	Conclusion	Area	Source
River water	Cr(VI)	0.002 mg·dm^{-3}	0.0031 mg·dm^{-3}	>1	risk	Maros, Indonesia	Rauf *et al.* (2021)
River water	Cr	0.003 mg·dm^{-3}	0.003–0.008 mg·dm^{-3}	>1	risk	Bangladesh	Hasan *et al.* (2021)
	Pb	0.01 mg·dm^{-3}	0.003–0.064 mg·dm^{-3}				
	Ni	0.07 mg·dm^{-3}	0.002–0.037 mg·dm^{-3}				
Surface water	*Cryptosporidium*	$<1 \cdot 10^{-4}$ CFU	0.216–0.064 mg·dm^{-3}	$2.1 \cdot 10^{-5}$	risk	Tehran, Iran	Hadi *et al.* (2019)
Ground water	Pb	0.003 mg·dm^{-3}	0.001–0.32 mg·dm^{-3}	>1	risk	Ondo State, Nigeria	Adesanya *et al.* (2020)
	Mn	0.4 mg·dm^{-3}					
Irrigation water	*Escherichia coli*	10^{-8}–10^{-4} CFU	126 CFU·(100 cm^3)$^{-1}$ *E. coli*	$9 \cdot 10^{-6}$	not risk	USA	Rock *et al.* (2019)
Well water	Cr(VI)	0.003 mg·dm^{-3}	0.0017 ±0.0006 mg·dm^{-3}	Cr(VI) > 1	not risk	Pangkajene, Indonesia	Astuti *et al.* (2021)
	Pb	0.01 mg·dm^{-3}	below detection limit	Pb > 1			
	Ni	0.07 mg·dm^{-3}	below detection limit	Ni > 1			
	Cd	0.002 mg·dm^{-3}	below detection limit	Cd < 1	risk		

Explanation: *RQ* = risk quotient.
Source: own elaboration based on literature.

Table 2. Components that affect Pb, Cr(VI), and Ni exposure risk

Variable exposure		Value: ingestion	Value: dermal	Unit
Exposure frequency (*EF*)		356	0	d·y^{-1}
Exposure time (*ET*)		2.6	0	hours per events
Exposure duration (*ED*)		adults = 30, children = 6		y
Average time (*AT*)		365 *ED*		d
Reference dose (*RfD*) (US EPA, 1996)	Cr(VI)	$3.00 \cdot 10^{-3}$	$6.00 \cdot 10^{-5}$	mg·kg^{-1}·d^{-1}
	Pb	$3.50 \cdot 10^{-3}$	$5.25 \cdot 10^{-4}$	
	Ni	$2.00 \cdot 10^{-2}$	–	

Source: US EPA (1996) and own study.

Table 3. Concentration of Pb, Cr(VI) and Ni in water samples

Sampling site	*RfD* ($mg \cdot kg^{-1} \cdot d^{-1}$)	Measured concentration ($Mg \cdot dm^{-3}$)			*RQ*			Conclusion		
		Pb	Cr(VI)	Ni	Pb	Cr(VI)	Ni	Pb	Cr(VI)	Ni
A1	Pb: $3.00 \cdot 10^{-3}$ Cr(VI): $3.50 \cdot 10^{-3}$ Ni: $2.00 \cdot 10^{-3}$ (US EPA, 1996)	0.0010	0.0090	0.0017	0.0090	0.0978	0.0029	not risk		
A2		0.0011	0.0087	0.0018	0.0095	0.1009	0.0031			
A3		0.0009	0.0085	0.0017	0.0068	0.0855	0.0026			
A4		0.0010	0.0092	0.0016	0.0062	0.0767	0.0021			
A5		0.0009	0.0096	0.0018	0.0454	0.0646	0.0018			
A6		0.0010	0.0097	0.0017	0.0059	0.0767	0.0020			

Explanations: *RfD* = reference dose, *RQ* = obtained risk quotient.
Source: own study.

0.0017 $mg \cdot dm^{-3}$ for Cr(VI) and 12.94 $mg \cdot dm^{-3}$ for SiO_2 in well water samples, indicating unacceptable drinking water quality in that area.

HEAVY METALS LEVEL AND RISK PREDICTION

An adverse effects can occur in humans due to exposure to heavy metals. Non-carcinogenic risk is usually called the risk quotient (*RQ*), resulting from calculating non-carcinogenic intake divided by the reference dose (*RfD*). In contrast, the carcinogenic risk is usually called excess cancer risk (*ECR*), resulting from calculating non-carcinogenic intake multiplied by the reference dose (slope factor) (Mahapatra *et al*., 2021).

The categorisation regards the volume of water supplied or produced in the supply zone according to the existing directive on the quality of water intended for human consumption. The degree to which a concentration provided for in law is exceeded is associated with an arbitrary threshold value adopted for indicators of exceedance applicable to water quality for consumption *EI*. The method then assumes a frequency of occurrence in which *EI* threshold values may occur during a year. Assumed values can be derived from waterworks practice and experience (Rak and Pietrucha-Urbanik, 2019).

As a criterion for drinking-water contamination, pollutant concentrations corresponding to individual physico-chemical indicators of composition were assumed. Next, the indicators included in the current standard for the quality of water intended for human consumption were divided into three groups, in line with their harmful effects on the human organism (Rak and Pietrucha-Urbanik, 2019).

1. The first group (A) includes indices determining the suitability of drinking water, such as colour, turbidity, iron, manganese, sulphates and chlorides, for which it is assumed that periodic and limited exceedances of normative concentrations do not threaten human health.
2. The next group (B) includes indicators that present a significant risk to human health. This includes forms of nitrogen and phosphorus, fluorides, chemical oxygen demand (COD), nanoparticles, hormones, antibiotics and pH.
3. The last group (C) includes indicators that pose a toxic threat to the human body, among others heavy metals, phenol, cyanides, and dichlorodiphenyltrichloroethane (DDT) and its metabolites.

The indicators from group A concern the pollutants least harmful to people, while group C indicators are substances *i.a.* having a carcinogenic impact.

Based on Figure 4, the *y*-axis represents the concentration values of Pb, Cr(VI) and Ni while the *x*-axis represents exposure (year). It is evident that the projected mean excess cancer risk (*ECR*) values for Pb, Ni, and Cr(VI) on the Supermonde Island. These values consistently increased from the 20th year to the 100 year period. The *ECR* values for Pb and Ni exposure show an annual increase and fall under the category of $ECR < 10^{-4}$ for the 20–100-year duration. In contrast, the *ECR* value for Cr(VI)

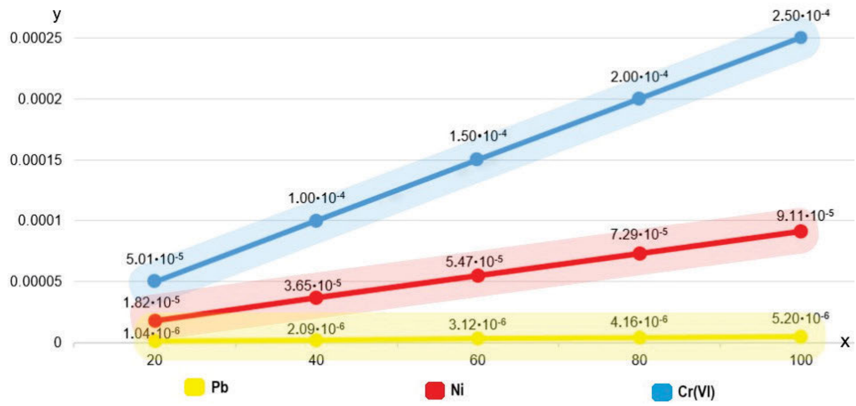

Fig. 4. Prediction of excess cancer risk (*ECR*) of Pb, N, and Cr(VI) exposure 100 years; source: own study

exposure increases annually and falls under the category of *ECR* > 10^{-4} for the 40–100-year duration, indicating a carcinogenic risk associated with Cr(VI) exposure that necessitates risk management. The risk level is considered acceptable or safe when the *ECR* is ≤ 10^{-4}, expressed as *ECR* ≤ 1/10,000. Conversely, the risk level is deemed unacceptable or unsafe if the *ECR* > 10^{-4}. The level of risk increases with the exposure duration (*ED*) or the time for prediction, leading to a higher risk level for individuals exposed to heavy metals.

In study by Rauf *et al.* (2021) conducted in the Pangkajene Islands, Indonesia, it was discovered that Cd, Ni, and Pb concentrations in community water sources were below detectable limit values. However, the average concentration of Cr(VI) was 0.0017 ±0.0006 $mg \cdot dm^{-3}$, with an *RQ* (risk quotient) value exceeding 1. This indicates that Cr(VI) exposure can harm the ecological system and human health (Rauf *et al.*, 2021). Various heavy metals present in water are known to cause various health problems. For instance, Ni is linked to respiratory tract cancer, Pb is associated with brain, kidney, and lung cancer, Cr(VI) is linked to lung cancer, Cd is associated with breast, lung, pancreas, and bladder cancer, and inorganic arsenic is linked to liver, prostate, and kidney cancers (Agbasi *et al.*, 2023).

These findings align with the research by Mohammadi *et al.* (2019) in Khorramabad, Iran, which indicated a cancer risk in the population associated with cumulative consumption of and skin contact with drinking water. Among the heavy metals investigated (Pb, Cr(VI), Cd, and Ni), Cr(VI) exhibited the highest cancer risk, with an average *ECR* of $6.54 \cdot 10^{-3}$. Conversely, Ni had the lowest cancer risk, with an average *ECR* of $9.16 \cdot 10^{-5}$ (Mohammadi *et al.*, 2019).

Hexavalent chromium Cr(VI) is a highly toxic and easily movable contaminant found in groundwater. The concentration of chromium in groundwater exhibits a positive correlation with groundwater depths. The presence of elevated levels of hexavalent chromium in deep well water is greatly influenced by hydrochemical characteristics like pH, E_h (redox potential), and the chemical composition of groundwater, including the coexistence of inorganic and organic substances (Li *et al.*, 2019).

Heavy metals presence in aquatic habitats significantly impacts aquatic organisms and can potentially affect the overall quality of human life (Astuti *et al.*, 2021). Prolonged exposure to potentially toxic heavy metals in water has been associated with considerable health damage in humans, particularly in organs such as the brain, liver, bones, and kidneys, where these metals tend to accumulate. Such exposure can impair central nervous system and mental functions, and adversely affect blood cells and other vital organs. Heavy metal concentrations exceeding the permissible levels set by the World Health Organization (WHO) have been shown to disrupt the body's metabolic processes. Regarding exposure routes, ingestion is the most common route, with infants and children being more susceptible than adults (Jabbo *et al.*, 2022). Furthermore, Ni significantly contributes to the overall cancer risk, accounting for an average of 81.7% (Adesanya *et al.*, 2020).

MICROBIAL RISK PRESENCE AND LEVEL RELATED TO DRINKING WATER

Table 4 shows that the bacteria identified in each drinking water sample on the Spermonde Island tend to be different. However, there were two drinking water samples, A1 and A2, which did not contain bacteria. Bacteria of *Escherichia coli* were found in sample A3, genus *Acinetobacter calcoaceticus* in sample A4, genus *Enterobacter* sp. in sample A5, and genus *Citrobacter* in sample A6. High exposure to pathogens was also found in samples A3, A4, A5, and A6, namely 0.069, 0.02, and 16, indicating contamination of the sample water. A similar study by Ismael *et al.* (2021) in the Red Sea State of Sudan, which was the first comprehensive survey of drinking water sources (both soil and surface), revealed that most of the locations did not meet safe limit standards. *Escherichia coli* and enterococci bacteria are typically found in the intestines of humans and animals. While most strains of *E. coli* are harmless and play a crucial role in maintaining a healthy intestinal tract, certain pathogenic strains can cause illnesses, including diarrhoea or diseases outside the intestinal tract (Farnleitner *et al.*, 2018).

The quantitative microbial risk assessment (QMRA), a process used to quantitatively assess the risk of infection and disease from pathogenic microorganisms, has been widely employed in evaluating water and food safety (Rock *et al.*, 2019). The results of the QMRA analysis include the probability of infection and the annual infection probability of pathogenic bacteria presence in drinking water on the Spermonde Island. These are presented in Table 3 with breakdown by the six samples. Samples A5 and A6 exhibited the highest probability of infection (P_{inf}) and annual probability of infection ($P_{inf/year}$) for pathogenic bacteria, both with the value of $P_{inf} = 1.59 \cdot 10^{-6}$ and $P_{inf/year} = 5.83 \cdot 10^{-4}$. The annual probability of disease for the population, also known as morbidity, is represented by $P_{ill/year}$ (Cao *et al.*, 2021).

Table 4. Microbial risk in drinking water samples ($B = 1.78 \cdot 10^6$, $\alpha = 0.1778$)

Sample	Bacteria	C_R	E	d	P_{inf}	$P_{inf/year}$	P_{ill}	Category
A1	no bacteria	0	0	0	0	0		no risk
A2								
A3	*Escherichia coli*	6.9	0.069	0.069	$6.9 \cdot 10^{-9}$	$2.51 \cdot 10^{-6}$		moderate risk
A4	*Acinetobacter calcoaceticus*	2.0	0.02	0.02	$2 \cdot 10^{-9}$	$7.3 \cdot 10^{-7}$		low risk
A5	*Enterobacter* sp.	1600	16	16	$1.59 \cdot 10^{-6}$	$5.83 \cdot 10^{-4}$		high risk
A5	*Citrobacter*	1600	16	16	$5.83 \cdot 10^{-4}$	$5.83 \cdot 10^{-4}$		high risk

Explanations: α and B = specified parameter numbers for the characteristics of O157:H7 pathogenic bacteria, C_R = concentration; E = exposure to drinking water pathogens, P_{inf} = probability of infection, $P_{inf/year}$ = annual probability of infection, P_{ill} = probability of illness.
Source: own study.

The World Health Organization (WHO) defines an acceptable risk of infection due to drinking water consumption as being less than 10^{-4} per person per year (WHO, 2008). The United States Environmental Protection Agency (US EPA) has established appropriate standards for various surface water treatment systems. Similarly, the Netherlands has implemented regulations for drinking water based on the recommendations of the WHO (Xiang *et al.*, 2019).

The QMRA analysis findings were assessed based on the safety thresholds established by the US EPA. According to these guidelines, the estimated average annual risk should be lower than 1 illness per 10,000 individuals exposed per year. This equates to a maximum permissible average daily risk of $2.7 \cdot 10^{-7}$ for the specific pathogen under evaluation, regardless of its origin. These standards are implemented to safeguard public health (Sano, Haas and Rose, 2019).

Table 4 presents the probability of health risks due to drinking water consumption on the Spermonde Island. Of the six samples, there are two samples within high categories, namely A5 and A6, each of (P_{ill}) $5.83 \cdot 10^{-4}$, and drinking water samples that are not at risk are A1 and A2. This research is in line with the annual probability of developing giardiasis from 45 water sources for individuals ($P_{ill/year}$) in the study conducted in Jintan, Ezhou, and Binyang in 2021 was $0–1.16 \cdot 10^{-3}$, $(5.45 \cdot 10^{-6})–(6.00 \cdot 10^{-4})$, and $0–1.27 \cdot 10^{-5}$, respectively (Cao *et al.*, 2021).

Individually sourced water, such as well water, carries a higher risk compared to other water sources (Barragan, Cuesta, and Susa, 2021). A World Health Organization report (WHO, 2004) indicates that approximately 80% of diseases worldwide and one-third of deaths in developing countries are attributed to contaminated drinking water (as cited in Ismael *et al.* (2021)).

In January 2019, a suspected cholera outbreak occurred in the Sembule village, Kampala City, Uganda, which was linked to the consumption of contaminated well water. The outbreak resulted from damage to the public water supply system (PDAM) that occurred a month before, forcing residents to rely on wells to meet their water needs. The wells were found to have a coliform count exceeding $900 \cdot (100\ cm^3)^{-1}$, indicating contamination (Eurien *et al.*, 2021).

ENVIRONMENTAL RISK MANAGEMENT IN SMALL ISLANDS

Upon completing the four steps of the EHRA, the assessment determines whether a risk agent is considered safe or acceptable. If the estimated cancer risk (*ECR*) value exceeds 1/10,000, risk management becomes necessary to mitigate the potential carcinogenic health effects due to heavy metal exposure. It should be noted that risk management is not an inherent part of the EHRA process but rather a subsequent action to be taken if the risk assessment results indicate an unsafe or unacceptable risk level, as per the EHRA technical guidelines issued by the Director General of P2PL at the Ministry of Health of the Republic of Indonesia (Direktorat Jenderal PP & PL, 2012).

Risk management aims to control factors contributing to health issues from using as drinking water sources shallow groundwater or well water containing heavy metals. In an agent-oriented approach to risk analysis, various variables such as heavy metal concentrations in the environment, duration of exposure, intake rate, and frequency of exposure are measured to determine the level of risk. Risk management involves implementing measures to control some of these variables and mitigate risks associated with exposure to harmful environmental agents.

One strategy for managing risks is to reduce heavy metal concentrations in drinking water sources to safe levels for daily consumption or use over a specific duration. The establishment of safe concentration thresholds for heavy metals may vary depending on the duration of exposure and the individual body weight.

In the context of pathogenic bacteria risks related to drinking water, the efforts made to control these risks are also considered risk management. Risk management involves developing policies and implementing risk controls to prevent or reduce health hazards caused by exposure to contaminated drinking water (US EPA, 2023). The quantitative microbial risk assessment (QMRA) analysis approach can be applied to establish preventive measures for such risks. The drinking water quality standards outlined in Regulation No. 32 of 2017, issued by the Minister of Health of the Republic of Indonesia, establish a safe limit of $50\ CFU \cdot (100\ cm^3)^{-1}$. This regulation defines the standards for environmental health quality and the hygiene requirements for water sanitation, swimming pools, Solus Per Aqua, and public baths.

Future considerations due to different water supply systems will form the basis of cost analysis and risk control effects. Like the lack of water supply, poor water quality creates costs that are borne by water producers and consumers. Therefore, it is necessary to determine the effectiveness of risk reduction by considering economic aspects and factors which form the basis of further research. Risk reduction can be done at the level of modernisation projects and preventive procedures, including solutions with backup and active protection that require operator intervention or supervision. The most effective solutions in terms of risk reduction should be implemented. This may also encourage more effective and frequent water quality checks, with a view to ensure that appropriate conditions are achieved.

LIMITATION

Even though this research has used a quantitative approach, the results obtained still have a probabilistic value. The research related to risk analysis has only been partial. For example, the microbial risk approach is the QMRA, while the chemical risk approach is the EHRA. Therefore, research must comprehensively combine microbial and chemical risks. It is difficult to make general conclusions because this approach is environment biased.

CONCLUSIONS

Unsanitary water conditions in coastal areas contribute to a range of health problems. Islanders often experience joint pain, mild to severe hearing loss, and conditions such as barotrauma and decompression sickness, commonly affecting divers. The EHRA considers the characteristics of the agent and the population to determine potential risks involved. The findings of the chemical and microbiological risk analysis conducted on a small island in the Spermonde Archipelago revealed that the concentrations of heavy metals in drinking water were below the thresholds: <0.0012 for Pb, <0.01 for Cr(VI), and <0.0019 for Ni. Risk assessment results indicated that the risk quotient (*RQ*) was below 1 for all samples, indicating no significant risk associated with these heavy metals. On the other hand, the microbial analysis identified the presence of *Escherichia coli*, *Acinetobacter calcoaceticus*, *Enterobacter* sp., and *Citrobacter*, with risk ranging from low to high.

Effective risk management strategies are necessary to mitigate the potential health hazards of consuming and using shallow groundwater or well water contaminated with heavy metals. In the agent-oriented risk analysis approach, various variables such as environmental heavy metal concentrations, exposure duration, intake rate, and frequency of exposure are measured to assess the level of risk. Island communities should definitely implement integrated water management. Due to is practicality, the management programme can be applied in other regions as well. The research results found a microbial risk. Thus, it is necessary to implement island-based integrated water management. The integrated water management programme can be carried out on other small islands. In terms of water use, people still rely on well water for their daily needs, while most of them use refilled drinking water for drinking.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

REFERENCES

Adesanya, O.O. *et al.* (2020) "Source identification and human health risk assessment of heavy metals in water sources around bitumen field in Ondo State, Nigeria," *Environmental Forensics*, pp. 1–12. Available at: https://doi.org/10.1080/15275922.2020.1850569.

Agbasi, J.C. *et al.* (2023) "Water pollution indexing and health risk assessment due to PTE ingestion and dermal absorption for nine human populations in Southeast Nigeria," *Groundwater for Sustainable Development*, 21, 100921. Available at: https://doi.org/10.1016/j.gsd.2023.100921.

Ahmed, J. *et al.* (2020) "Quantitative microbial risk assessment of drinking water quality to predict the risk of waterborne diseases in primary-school children," *International Journal of Environmental Research and Public Health*, 17(8), 2774. Available at: https://doi.org/10.3390/Ijerph17082774.

Amatobi, D.A. and Agunwamba, J.C. (2022) "Improved quantitative microbial risk assessment (QMRA) for drinking water sources in developing countries," *Applied Water Science*, 12(3), 49. Available at: https://doi.org/10.1007/S13201-022-01569-8.

Astuti, R.D.P. *et al.* (2021) "Risk identification of heavy metals in well water surrounds watershed area of Pangkajene, Indonesia," *Gaceta Sanitaria*, 35, pp. S33–S37. Available at: https://doi.org/10.1016/j.gaceta.2020.12.010.

Barragan, J.L.M., Cuesta, L.D.I. and Susa, M.S.R. (2021) "Quantitative microbial risk assessment to estimate the public health risk from exposure to enterotoxigenic *E. coli* in drinking water in the rural area of Villapinzon, Colombia," *Microbial Risk Analysis*, 18, 100173. Available at: https://doi.org/10.1016/J.Mran.2021.100173.

Barrang Lompo Health Center (2012) *Source of clean water for the community in the working area of the Barrang Health Center*. Makassar.

Bevacqua, A., Yu, D. and Zhang, Y. (2018) "Coastal vulnerability: Evolving concepts in understanding vulnerable people and places," *Environmental Science and Policy*, 82, pp. 19–29. Available at: https://doi.org/10.1016/j.envsci.2018.01.006.

Birawida, A.B. (2019) *Kesehatan pesisir wilayah pesisir dan kepulauan [Environmental health for coastal and small island]*. Makassar: Universitas Hasanuddin. Available at: https://www.researchgate.net/publication/335790162_Kesehatan_Lingkungan_Pesisir_-dan_Kepulauan (Accessed: May 15, 2023).

Birawida, A.B. *et al.* (2021) "Clean water supply vulnerability model for improving the quality of public health (environmental health perspective): A case in Spermonde Islands, Makassar Indonesia," *Gaceta Sanitaria*, 35, pp. S601–S603. Available at: https://doi.org/10.1016/j.gaceta.2021.10.095.

Cao, S.K. *et al.* (2021) "Quantitative microbial risk assessment of *Cryptosporidium* and *Giardia* in public drinking water in China," *Biomedical and Environmental Sciences*, 34(6), pp. 493–498. Available at: https://doi.org/10.3967/bes2021.068.

Dewi, N. (2019) "Degree of island community health on Hiri Island in 2019," *Kieraha Medical Journal*, 1(2), pp. 15–18. Available at: https://doi.org/10.33387/kmj.v1i2.1702.

Direktorat Jenderal PP & PL (2012) *Pedoman analisis risiko kesehatan lingkungan [Guidelines for environmental health risk analysis]*. Jakarta: Direktorat Jenderal PP dan PL Kementerian Kesehatan. Available at: https://www.academia.edu/22127843/PEDOMAN_ANALISIS_RISIKO_KESEHATAN_LINGKUNGAN (Accessed: May 15, 2023).

Doorga, J.R.S. (2022) "Climate change and the fate of small islands: The case of Mauritius," *Environmental Science & Policy*, 136, pp. 282–290. Available at: https://doi.org/10.1016/J.Envsci.2022.06.012.

Ersel, M. (2015) "Water and sanitation standards in humanitarian action," *Turkish Journal of Emergency Medicine*, 15, pp. 27–33. Available at: https://doi.org/10.5505/1304.7361.2015.48753.

Eurien, D. *et al.* (2021) "Cholera outbreak caused by drinking unprotected well water contaminated with faeces from an open storm water drainage: Kampala City, Uganda, January 2019," *BMC Infectious Diseases*, 21(1), 1281. Available at: https://doi.org/10.1186/S12879-021-07011-9.

Farnleitner, A.H. *et al.* (2018) "Integrated strategy to guide health-related microbial quality management at alpine karstic drinking water resources," in W. White *et al.* (eds.) *Karst groundwater contamination and public health. Advances in Karst Science*. Cham: Springer International Publishing, pp. 185–192. Available at: https://doi.org/10.1007/978-3-319-51070-5_20.

Hadi, M. *et al.* (2019) "Optimizing the performance of conventional water treatment system using quantitative microbial risk assessment, Tehran, Iran," *Water Research*, 162, pp. 394–408. Available at: https://doi.org/10.1016/j.watres.2019.06.076.

Hasan, M.F. *et al.* (2021) "Health risk and water quality assessment of surface water in an urban river of Bangladesh," *Sustainability*, 13(12), 6832. Available at: https://doi.org/10.3390/su13126832.

Heston, Y.P. and Alvira, N. (2021) "Problem and technology solution improving water quality in Morotai Island (A case study in Koloray, Muhajirin and Juanga)," *Technology in Society*, 101552. Available at: https://doi.org/10.1016/j.techsoc.2021.101552.

Ismael, M. *et al.* (2021) "Assessing drinking water quality based on physical, chemical and microbial parameters in the Red Sea State, Sudan using a combination of water quality index and artificial neural network model," *Groundwater for Sustainable Development*, 14, 100612. Available at: https://doi.org/10.1016/J.Gsd.2021.100612.

Jabbo, J.N. *et al.* (2022) "Geochemometric approach to groundwater quality and health risk assessment of heavy metals of Yankari

Game Reserve and its environs, Northeast Nigeria," *Journal of Cleaner Production*, 330, 129916. Available at: https://doi.org/10.1016/j.jclepro.2021.129916.

Jiang, S.C. *et al.* (2020) "Assessing the water quality impacts of two category-5 hurricanes on St. Thomas, Virgin Islands," *Water Research*, 171, 115440. Available at: https://doi.org/10.1016/j.watres.2019.115440.

Kao, S.-M., Wu, W.-N. and Gu, M.-E. (2023) "Coastal disaster protection and hazard perceptions of the residents of Orchid Island, Taiwan," *Marine Policy*, 148, 105459. Available at: https://doi.org/10.1016/j.marpol.2022.105459.

Ledoh, L.Y, Satria, A. and Hidayat, R. (2019) "Kerentanan penghidupan masyarakat pesisir perkotaan terhadap variabilitas iklim (Studi kasus di Kota Kupang) [Vulnerability of livelihoods of urban coastal communities to climate variability (Case study in Kupang City)]," *Journal of Natural Resources and Environmental Management*, 9(3), pp. 758–770. Available at: http://dx.doi.org/10.29244/jpsl.9.3.758-770.

Li, Y. *et al.* (2019) "The distribution and influencing factors of chromium in regional groundwater at Sanmenxia Basin north-central China," *Desalination and Water Treatment*, 150, pp. 114–123. Available at: https://doi.org/10.5004/dwt.2019.23633.

Mahapatra, P.S. *et al.* (2021) "Chemical, microstructural, and biological characterization of wintertime $PM_{2.5}$ during a land campaign study in a coastal city of Eastern India," *Atmospheric Pollution Research*, 12(9), 101164. Available at: https://doi.org/10.1016/j.apr.2021.101164.

Maolani, R.A. *et al.* (2021) "Perluasan hutan mangrove dalam mitigasi risiko bencana bemanasan global: Kegiatan PkM di kawasan pesisir Muara Angke Jakarta [Expansion of mangrove forests in mitigating the risk of global warming disasters: PKM activities in the coastal area of Muara Angke Jakarta]," *Dinamisia: Devotion Journal to the Community*, 5(6), pp. 1380–1388. Available at: https://doi.org/10.31849/dinamisia.v5i6.8096.

Mohammadi, A.A. *et al.* (2019) "Carcinogenic and non-carcinogenic health risk assessment of heavy metals in drinking water of Khorramabad, Iran," *MethodsX*, 6, pp. 1642–1651. Available at: https://doi.org/10.1016/j.mex.2019.07.017.

Papapostolou, C.M. *et al.* (2020) "Sustainable water supply systems for the islands: The integration with the energy problem," *Renewable Energy*, 146, pp. 2577–2588. Available at: https://doi.org/10.1016/j.renene.2019.07.130.

Peraturan (2010) Peraturan Menteri Kesehatan Republik Indonesia Nomor 492/MENKES/PER/IV/2019 tentang Persyaratan kualitas air minum [*Regulation of the Minister of Health of the Republic of Indonesia Number 492/MENKES/PER/IV/2019 concerning Drinking Water Quality Requirements*]. Jakarta: Menteri Kesehatan Republik Indonesia. Available at: https://stunting.go.id/kemenkes-permenkes-no-492-tahun-2010-tentang-persyaratan-kualitas-air-minum/ (Accessed: May 15, 2023).

Rak, J.R. and Pietrucha-Urbanik, K. (2019) "An approach to determine risk indices for drinking water–study investigation," *Sustainability* 11(11), 3189. Available at: https://doi.org/10.3390/su11113189.

Rauf, A.U. *et al.* (2021) "Ecological risk assessment of hexavalent chromium and silicon dioxide in well water in Maros Regency, Indonesia," *Gaceta Sanitaria*, 35, pp. S4–S8. Available at: https://doi.org/10.1016/j.gaceta.2020.12.002.

Rekomendasi (2022) *Rekomendasi persetujuan etik Nomor: 2507/UN4.14.1/TP.01.02/2022 [Recommendation for ethical approval Number: 2507/UN4.14.1/TP.01.02/2022]*. Ministry of Education, Culture, Research, and Technology. Hasanuddin University. Faculty of Public Health.

Rock, C.M. *et al.* (2019) "Review of water quality criteria for water reuse and risk-based implications for irrigated produce under the FDA Food Safety Modernization Act, produce safety rule," *Environmental Research*, 172, pp. 616–629. Available at: https://doi.org/10.1016/j.envres.2018.12.050.

Sano, D., Haas, C. and Rose, J. (2019) "A QMRA framework for sanitation treatment decisions," in J.B. Rose and B. Jiménez-Cisneros (eds.) P. 1. *The health hazards and excreta: Theory and control.* E. Lansing, MI: Michigan State University, UNESCO.

SNI 6989.58:2008. *Air dan air limbah – Bagian 58: Metoda pengambilan contoh air tanah [Methodology of taking groundwater samples]*. Jakarta: Badan Standardisasi Nasional.

Subagiyo, A., Wijayanti, W.P. and Zakiyah, D.M. (2017) *Management of coastal areas and small islands*. Universitas Brawijaya Press.

Surira, M.R. *et al.* (2020) "Characteristics of home environment factors and community behavior of endemic malaria area in Jampea Island," *Enfermeria Clinica*, 30, pp. 448–451. Available at: https://doi.org/10.1016/j.enfcli.2020.03.008.

Syamsir, Birawida, A.B. and Faisal, A. (2019) "Development of water quality index of island wells in Makassar City," *Journal of Physics: Conference Series*, 1155(1). Available at: https://doi.org/10.1088/1742-6596/1155/1/012106.

US EPA (1996) "Eco update: Ecotox thresholds," *Intermittent Bulletin*, 3(2), pp. 1–11. Available at: https://www.epa.gov/sites/production/files/2015-09/documents/v3no2.pdf (Accessed: May 15, 2023).

US EPA (2023) *Report on the Environment. Land*. New York: U.S. Government Printing Office: Environmental Protection Agency. Available at: https://www.epa.gov/report-environment/land (Accessed: May 15, 2023).

WHO (2008) *Guidelines for drinking-water quality*. 3rd edn. Geneva, Switzerland: World Health Organization. Available at: https://www.epa.gov/sites/default/files/2014-03/documents/guidelines_for_drinking_water_quality_3v.pdf (Accessed: May 15, 2023).

Wu, H. *et al.* (2020) "Heavy metal pollution and health risk assessment of agricultural soil near a Smelter in an industrial city in China," *International Journal of Environmental Health Research*, 30(2), pp. 174–186. Available at: https://doi.org/10.1080/09603123.2019.1584666.

Xiang, R. *et al.* (2019) "Isolation distance between municipal solid waste landfills and drinking water wells for bacteria attenuation and safe drinking," *Scientific Reports*, 9(1), 17881. Available at: https://doi.org/10.1038/S41598-019-54506-2.

Yang, J. *et al.* (2022) "Multiple risk assessment of heavy metals in surface water and sediment in Taihu Lake, China," *International Journal of Environmental Research and Public Health*, 19(20), 13120. Available at: https://doi.org/10.3390/ijerph192013120.