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*Research Article*

# Microbial Quantitative Risk Assessment in Springs as Community Drinking Water Sources in the Banggai Islands Karst Area, Central Sulawesi

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## ABSTRACT

The Banggai Karst Area of the Islands of Central Sulawesi Province is dominated by the appearance of the Karst Ecosystem, which covers 97% of the total area, so it is very vulnerable to pathogenic bacterial contamination. This type of research is an observational study with a Cross-Sectional design with an Environmental Health Risk Assessment (EHRA) approach method to assess or forecast the amount of human health risk caused by exposure to environmental hazards. Quantitative microbial risk assessment (QMRA) determines or predicts the human health risk caused by exposure to environmental hazards from pathogenic bacterial contamination. In this study, we collected 230 human samples and four samples of springs as a source of community drinking water, namely Paisu Lalomo Spring in South Buko District, Paisu Taabak in Liang District, Paisu Olulan in North Bulagi District and Paisu Sinangkal North Tinangkung District. The examination results on four springs as a source of community drinking water contained one sample with the highest probability of infection (Pinf) of $3.92 \times 10^{-4}$, namely Coliform bacteria in Paisu Lalomo springs.

Furthermore, the annual chance of infection (Pinf / year), the highest pathogenic bacteria, was also found in Paisu Lalomo spring samples, namely in coliform bacteria with the same value (Pinf / year) = $1.32 \times 10^{-1}$. However, examination of other bacteria also showed that all positive springs contained coliform bacteria and Enterococcus exceeding the specified limit (1x10-4). Risk management is needed to control risk factors that can cause health problems due to consuming and utilizing springs as a source of drinking water.

**Keywords:** QMRA, Pathogenic bacteria, Karst, Springs.

## INTRODUCTION

Sustainable Development Goals are global agreements to end poverty, reduce inequality, and protect the environment[1]. SDGs goal 7 is to ensure the availability and sustainable management of clean water and sanitation for all[2] (WHO, 2019). Targets by 2030: Improve water quality by reducing pollution, eliminating waste disposal and minimizing the removal of chemicals and hazardous materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe reuse globally[2]

The extraction or utilization of karst springs to meet various needs from year to year always increases, in line with the increasing population and growing needs of the community[3]. The ever-increasing need for water causes humans to forget that the environment's carrying capacity has limits in meeting domestic and other needs such as industry, agriculture, and urban needs[4]

Factors that affect the quantity and quality of karst springs in the future, including land cover conditions in rainwater catchment areas, land use activities in rainwater catchment areas, geomorphological and geological conditions, as well as consumption patterns or utilization of spring sources to meet population needs that are highly dependent on regional development and population growth[5].

The quality of groundwater in a region is largely determined by natural processes (lithology, groundwater velocity, affix water quality, and interaction with other types of aquifers) and anthropogenic activities (agriculture, industry, urban development) and increased exploitation of water resources [6].

Land use is one of the most critical factors determining water quality. However, very few studies have focused on the impacts of land use and land cover change on karst hydrogeochemical systems. As a sensitive ecosystem, the karst environment controls the karst dynamics system. As a factor in vulnerable karst ecosystems, karst groundwater systems are susceptible to land use and land cover change.

Pollution in karst aquifers is closely related to the level of water permeability because it can recharge karst aquifers. Therefore, the movement of pollutants from heavy metals, human and livestock feces from residential and grazing areas, chemicals in agricultural and plantation activities, and karst aquifers will be contaminated by microbes and chemicals. Periodic rainfall can cause rapid water recharge and impact the discharge and transport of heavy metals and microbes to karst springs, making Karst groundwater sources highly vulnerable to heavy metal contamination and pathogenic microbes caused by the ingress of rainwater into karst channels

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with little filtration within their hydrological systems[7]. The condition of waters containing bacteria is triggered by unhealthy lifestyles, such as most people building houses on the sea so they do not have septic tanks and dispose of their waste directly into the sea[8,9] research found that among 22 freshwater samples, 86% were Legionella positive, and 82% were Escherichia-Shigella positive. Enterococcus fecal was detected in over 68% of reservoir rainfall and 60% of coastal waters[10]

Researches relate to waters bacteria pollutantsfound that pathogenic bacteria pollute more than 62% of water sources in developing countries[11]. The average concentration of Escherichia coli bacteria was 0.325 with a disease risk level of 0.065; Salmonella spp of 0.227 with a disease risk level of 0.045; Shigella spp of 0.240 with a disease risk level of 0.031; Campylobacter of 0.255 with a disease risk level of 0.026; Giardia lamblia at 0.218 with a disease risk level of 0.044; Cryptosporidium parvum is 0.153 with a disease risk level of 0.021. The mean risk of diarrheal disease based on all pathogens was 0.039, with a standard deviation of 0.016 [12].

The area of the Banggai Islands Regency is dominated by the appearance of Karst Ecosystems, which covers 97.7% or 232,843 hectares of the total area of the Banggai Islands Regency[13]. This study is located in most areas that have karst hydrological characteristics. Karst hydrology has unique characteristics in contrast to the general hydrological system in other rocks. Karst is a landscape characterized by caves and underground hydrology (underground rivers), which develop on easily soluble rocks. Soluble rocks are a prerequisite for developing karst landscapes, limestone in the Banggai Islands Regency case. Because karst landscapes develop in easily soluble limestone, the dominant hydrological and geomorphological processes in the study area are dissolving processes[14]. Pollution in karst aquifers is closely related to the level of water permeability because it can recharge karst aquifers. Periodic rainfall can cause rapid water recharge and impact the discharge and transport of heavy metals and microbes to karst springs, making Karst groundwater sources particularly vulnerable to pathogenic microbial contamination caused by the ingress of rainwater into karst channels with little filtration within their hydrological systems[7].

Most studies analyzing heavy metal contaminants and pathogenic microbes use combined water quality analysis results and remote sensing data to compare the results of water quality analysis before and after land use and land cover change[15]. This research has a novelty value in the form of a control strategy and environmental health risk analysis to prevent pollution in community drinking water in the Banggai Islands Karst Area. In addition, research on pathogenic microbes in springs in karst areas, especially in the Banggai Islands Regency, still needs to be completed. At the same time, Banggai Islands Regency, because it is a karst area that reaches 80% - 90% of the land area, has a reasonably dense population consisting of 12 sub-districts and 144 villages/villages. Most of the community's drinking water sources are springs of limited quality and quantity.

The results of these studies have important implications for public health and the protection of springs in the Banggai Karst Islands Area. They may also be interested in the broader science of specific communities, as they provide valuable information about the health risks associated with pathogenic microbe contamination in spring water. In the absence of research on the risk of pathogenic microbes in springs to human health, the magnitude of the impact of water pollution on public health requires risk analysis steps to determine appropriate actions. Therefore, this study aims to determine the level of health risk of people who consume drinking water containing pathogenic microbes in Banggai Islands Karst Area.

# METHOD

## Area of Study

Karst Banggai Islands has a vital role in supporting the life of living things because it can absorb millions of cubic meters of rainwater every year to meet a quarter of the clean water needs of its population. This karst region also plays a role in absorbing CO2 from the atmosphere. The certification process will re-release CO2, so the average CO2 absorbed is significant. Household waste, human feces, and livestock feces are the leading causes of pathogenic microbial contamination in springs as a source of drinking water for communities in the Banggai Islands. Figure 1 shows the location of springs as a source of drinking water for the community in the Banggai Islands Karst Area, namely Paisu Lalomo Springs in South Buko District, Paisu Taabak in Liang District, Paisu Olulan in North Bulagi District and Paisu Sinangkal in North Tinangkung District.

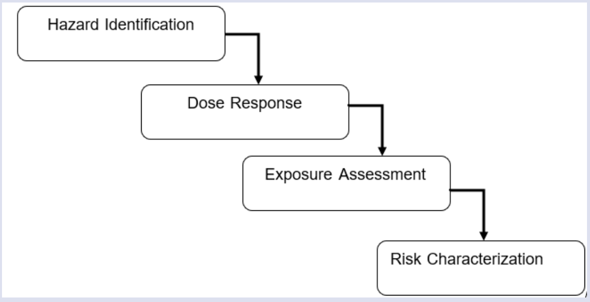
## Criteria for contamination of drinking water

As a criterion of contamination of drinking water, it is assumed that the concentration of pollutants corresponds to individual physicochemical composition indicators. Further, the indicators included in the water quality standards for human consumption are currently divided into three groups according to their harmful impact on the human organism[16].

A. The first group (A) includes indices that determine the suitability of drinking water, among others, color, turbidity, iron, manganese, sulfate, and chloride, which assume that periodic and limited exaggerations of normative concentrations do not threaten human health,

B. The next group (B) includes indicators that pose a significant risk to human health. Included here are forms of nitrogen and phosphorus,

**Figure 1.** Location of Springs in the Karst Area of Banggai Islands.



*Source:*[17, 18].

**Figure 2.** Stages of Quantitative Microbial Risk Assessment (QMRA).

fluoride, Chemical Oxygen Demand (COD), nanoparticles, hormones, antibiotics, and pH,

C. The last group (C) includes indicators that pose a toxic threat to the human body: heavy metals, phenols, cyanides, and DDT and their metabolites. Therefore, indicators of group A relate to pollutants that are least harmful to humans, while indicators of group C are substances that have a thermogenic impact.

Microbial quantitative risk assessment (QMRA) uses four steps to determine the likelihood of infection and focuses on the impact of disease, shown in Figure 2.

Figure 2 above presents the stages of conducting a Quantitative Microbial Risk Assessment, namely

1. Hazard identification is the first step in QMRA, which causes health problems if the body is exposed.
2. Perform a dose-response analysis expressed as the number of organisms (CFU/100 ml of drinking water sample) to understand the risk agent's effects on the human body.
3. Conduct exposure analysis by measuring or calculating the intake of risk agents.
4. Risk Characterization: Characterization brings exposure and dose response together and eliminates the possibility of infection, disease, and death for heavy metals or pathogens of concern, addressing assumptions variability/uncertainty[17,18].

Microbial quantitative risk assessment (QMRA) is the level of microbial pathogens in the environment and the determination of treatment required to reduce the risk and ensure an acceptable level of public health safety at a particular end point of use (Sano, Haas, & Rose, 2019). Dose-response (DR) assessment characterizes the relationship between the amount of pathogen ingested (dose) and the likelihood of adverse consequences related to infection, disease, or death. The β-Poisson dose-response model is shown in Equation (1)[19]

$$\frac{P\ inf}{day} = 1 - \left[1 + \left(\frac{d}{N50}\right)\right]\left(2^{\frac{1}{\infty}} - 1\right) \qquad (1)$$

where d is the dose, N50 is the dose corresponding to the median response, and alpha is the distribution parameter. For risk characterization, the annual probability of infection and the probability of disease are determined using standard equations. The annual probability of infection is calculated through Equation (2):

$$P\ \mathrm{inf}\,annual = 1 - [\,1 - \frac{Pinf}{day}]^{n} \qquad (2)$$

Where the probability of infection per day (Pinf/day) is obtained from Equation (1) above, and n is the number of days of exposure in a year. The probability of disease is calculated by Equation (3):

$$Pill = P\ in\ annual\ x\ Pill/inf \qquad (3)$$

The pill/inf is the probability of disease per infection, and the annual inf P is defined in the Equation.

## RESULTS

The results of laboratory tests of the Makassar Health Laboratory Center (BBLK) on water quality parameters (springs) measured at the time of the study, namely Microbiology in detail, can be seen as follows:

Table 2 It is described that in Lalomo water sources found 200000 coliforms and 35 Enterococcus, but in Taabak, 9400 coliform, 23 Enterococcus, 24 Staphylococcus, and 40 Pseudomonas, while in Olulan, 63000 Coliform, 400 E.Coli, 11 Enterococcus, and 92 Staphylococcus, and financial springs found 8200 coliform. 800 E. coli, 84 Enterococcus, and 53 Staphylococcus. Each positive spring contains Coliform and Enterococcus bacteria.

## Hazard Identification

Hazard identification is done by examining pathogenic bacteria types in water samples (springs) in the BBLK laboratory. In quantitative risk analysis, to determine exposure to drinking water pathogens (E), it is described in the following Equation:

$$E = CR \times (1 - PT) \qquad (4)$$

Information:

E: Exposure to pathogens in drinking water

CR: Drinking water quality (organisms per liter)

PT: Processing effectiveness (0,99)

Based on Table 3. It is known that the average exposure distribution to pathogenic bacteria comes from Lalomo springs, namely from Total Coliform (Cf) bacteria of 2000, but for all springs, the distribution of total coliform bacterial exposure. The average exposure distribution of pathogens comes from Pseudomonas (Ps) bacteria, found only in Taabak Springs with several 0.4.

## Dose-Response Assessment

In the dose-response analysis stage, the researcher calculates the probability of the dose/number of bacteria ingested. The pathogen dose is expressed as the number of organisms (CFU/100 ml drinking water sample). The formula used to determine the estimated dose/number of bacteria ingested per day (d):

$$d = E \times V \qquad (5)$$

Information:

d: Estimated dose/number of ingested bacteria

E: Exposure to pathogens in drinking water

V: Volume of drinking water consumed (liters)

Table 4 presents the distribution of response dose analysis in average respondents dominated by total coliform (Cf) bacteria because it produces high response dose calculations in all spring water sources. Pseudomonas bacteria are known to produce low dose-response calculations from four springs.

## Exposure assessment

Exposure analysis determines the route, frequency, duration, and magnitude (amount) of microbial hazard exposure in a population. Calculation of exposure analysis with the following formula:

Probability of infection $(P_{inf})$ =

$E \times r$ or $(P_{inf}) = 1 - (1 + \frac{d}{\beta})^{-\alpha}$ (6)

Information:

Pinf: Probability of infection

r: Dose-response

d: Estimated dose/number of ingested bacteria

E: Exposure to pathogens in drinking water

α: 0,1778 (Determination of characteristic parameters of pathogenic bacteria)

β: 1780000 (Determination of characteristic parameters of pathogenic bacteria)

**Table 1.** World Bacteriological Examination Synthesis Table.

| Sample | Materials | Ref. Level of Risk | Measured of Concentration | RQ | Conclusion | Area | Source |
|---|---|---|---|---|---|---|---|
| Surface Water | Cryptosporidium | Pinf ;a < $10^{-4}$ | 0.216 - 0.064 oocysts/L, | 2.1 x $10^{-5}$ | Risky | Theran, Iran | [20] |
| Irrigation Water | *Escherichia coli* | $10^{-8}$ – $10^{-4}$ | 126 CFU/100 mL E. coli | 9 x $10^{-6}$ | No Risk | | [21] |
| Karst area springs | *Escherichia coli* | Pill = 0.35 | - | - | Risky | Romanian | [22] |
| - | - | - | - | - | - | Banggai Islands, Indonesia | Now. |

**Table 2.** Frequency Distribution Based on Microbiological Content.

| Sample | Microbiological Parameters | | | | | Unit | Drinking Water Quality Standards* |
|---|---|---|---|---|---|---|---|
| | Total coliform | Eschericia coli | Enterococcus | Staphylococcus sp | Pseudomonas sp | | |
| Lalomo | 200000 | 0 | 35 | 0 | 0 | CFU/100 ML | 1000 |
| Taabak | 9400 | 0 | 23 | 24 | 40 | CFU/100 ML | 1000 |
| Olulan | 6300 | 400 | 11 | 92 | 0 | CFU/100 ML | 1000 |
| Sinangkal | 8200 | 800 | 84 | 53 | 0 | CFU/100 ML | 1000 |

*Source: Primary Data (2023)*

**Table 3.** Distribution of average exposure to pathogens.

| Sample | E Cf | E Ec | E Etr | E Stp | E Ps |
|---|---|---|---|---|---|
| Lalomo | 2000 | 0 | 0.35 | 0 | 0 |
| Taabak | 94 | 0 | 0.23 | 0.24 | 0.4 |
| Olulan | 63 | 4 | 0.11 | 0.92 | 0 |
| Sinangkal | 82 | 8 | 0.84 | 0.53 | 0 |

*Source: Primary Data (2023)*

**Table 4.** Average Analysis Distribution Dosis-Respon.

| Sample | d Cf | d Ec | d Etr | d Stp | d Ps |
|---|---|---|---|---|---|
| Lalomo | 3925 | 0 | 0.69 | 0 | 0 |
| Taabak | 188 | 0 | 0.46 | 0.48 | 0.8 |
| Olulan | 122.1 | 7.75 | 0.21 | 1.78 | 0 |
| Sinangkal | 110.7 | 10.8 | 1.13 | 0.715 | 0 |

Sumber : Data Primer (2023)

**Table 5.** Distribution of Probability of Infection (PINF) Analysis.

| Sample | Pinf Cf | Pinf Ec | Pinf Etr | Pinf Stp | Pinf Ps |
|---|---|---|---|---|---|
| Lalomo | 0.000392 | 0 | 6.861E-08 | 0 | 0 |
| Taabak | 1.88E-05 | 0 | 4.59E-08 | 4.79E-08 | 7.99E-08 |
| Olulan | 1.22E-05 | 7.74E-07 | 2.13E-08 | 1.78E-07 | 0 |
| Sinangkal | 1.11E-05 | 1.08E-06 | 1.13E-07 | 7.15E-08 | 0 |

*Source: Primary Data (2023)*

**Table 6.** Probability of infection/year Analysis Distribution.

| Sample | Pinf/yr Cf | Pinf/yr Ec | Pinf/yr Etr | Pinf/yr Stp | Pinf/yr Ps |
|---|---|---|---|---|---|
| Lalomo | 0.13259 | 0 | 2.5E-05 | 0 | 0 |
| Taabak | 0.00683 | 0 | 1.68E-05 | 1.75E-05 | 2.92E-05 |
| Olulan | 0.00444 | 0.000283 | 7.77E-06 | 6.5E-05 | 0 |
| Sinangkal | 0.00402 | 0.000394 | 4.13E-05 | 2.61E-05 | 0 |

Source: Primary Data (2023)

**Table 7.** Probability of infection/year Analysis Distribution.

| Sample | Pill Cf | Pill Ec | Pill Etr | Pill Stp | Pill Ps |
|---|---|---|---|---|---|
| Lalomo | 5.52E-05 | 0 | 1.835E-12 | 0 | 0 |
| Taabak | 1.33E-07 | 0 | 7.96E-13 | 8.67E-13 | 2.41E-12 |
| Olulan | 5.75E-08 | 2.32E-10 | 1.76E-13 | 1.23E-11 | 0 |
| Sinangkal | 5.01E-08 | 4.78E-10 | 5.27E-12 | 2.1E-12 | 0 |

*Sumber : Data Primer (2023)*

**Table 8.** **Probability of infection/year Analysis Distribution.**

| Sample | Cf Risk | Ec Risk | Etr Risk | Stp Risk | Ps Risk |
|---|---|---|---|---|---|
| Lalomo | LR* | NR** | HR*** | NR | NR |
| Taabak | HR | NR | HR | HR | HR |
| Olulan | HR | HR | HR | HR | NR |
| Sinangkal | HR | HR | HR | HR | HR |

'* = Low Risk
'** = Not Risk
'*** = High Risk

The results of calculating the risk of QMRA infection are also presented in Table 5. shows the probability of infection and the annual probability of pathogenic bacterial infection in springs in the Banggai Karst Area of the Islands, Central Sulawesi; from four sample springs, there is one sample with the highest probability of infection (Pinf) of 3.92 x10-4, namely Coliform bacteria in Lalomo springs.

## Annual Infection Probability Analysis

An annual probability of infection analysis is carried out to determine the risk of infection within one year, then the following formula is used:

$$P_{\text{infection/year}} = 1 - (1 - P_{\text{infection}})^{365} \qquad (7)$$

Information:

Perfection$_{\text{/year}}$: Annual probability of infection

P$_{\text{inf}}$: Probability of infection

The annual chance of infection (Pinf/year) shown in Table 6 shows the highest pathogenic bacteria were also found in Lalomo spring samples, namely coliform bacteria with the same value (Pinf/year) = 1.32×10-1. However, examination of other bacteria also showed that all positive springs contained coliform bacteria and Enterococcus exceeding the specified limit (1x10-4).

## Risk Characteristic Analysis

Risk characteristics are carried out to determine the level of risk due to exposure to microbial hazards that enter the body, expressed in the Risk of Illness value. Calculation of Risk of Illness with the following formula:

$$\text{Risk of Illness (PiII)} = \text{Pinfection/year} \times \text{Pill/inf} \qquad (8)$$

Information:

Risk of Illness (PiII): Probability of risk of pain

Perfection/year: Annual probability of infection

Pll/info: The rating that has been given an infection value is 1

Table 7 displays the distribution of the annual probability or probability of infection. The highest annual probability of infection was found from total coliform (Cf) bacteria of 5.52E-05 or 5.52x10-5 in Lalomo Springs. At the same time, the lowest annual infection probability was found in Taabak spring water, with an annual infection probability of 8.67E-13 or 8.67x10-13, namely from Staphylococcus bacteria (Stp).

## Health Risk Analysis

According to the WHO drinking water guidelines, the standard risk reference level is 10-6. If the value of Pinf.d/PiII is greater than 10-6 (e.g., 10-5), then the risk is high, while if the value of Pinf.d/PiII is less than 10-6 (e.g., 10-7), then the risk is low. As for if the value of Pinf.d / PiII = 10-6, then it is assumed to have moderate risk.

Table 8 presents possible health risks to drinking springs in the Banggai Karst Archipelago, Central Sulawesi. Of the four samples from various types of bacteria, it is known that all water samples have a high risk even though they are different types of bacteria.

# DISCUSSION

The results of examinations on four springs as a source of drinking water for the community in the Banggai Karst Area of the Islands, Central Sulawesi, found that the four springs were positive for containing various bacteria that had exceeded the threshold and could be detrimental to health, in table 1. Paisu Lalomo found 200,000 coliforms and 35 Enterococcus in the water source. However, in Taabak 9400 coliform, 23 Enterococcus, 24 Staphylococcus, and 40 Pseudomonas, while in Paisu Olulan 63000 Coliform, 400 E.Coli, 11 Enterococcus, and 92 Staphylococcus, and in the spring Paisu Sinangkal found 8200 coliform. 800 E. coli, 84 Enterococcus, and 53 Staphylococcus. Each positive spring contains Coliform and Enterococcus bacteria.

In many parts of the world, karst aquifers are among the most important freshwater resources. However, it is susceptible to microbial and other contamination. Karst systems often flow into springs, the preferred locations for drinking water abstraction[23]. Karst areas are known to be susceptible to bacterial contamination that is detrimental to human health. Karst aquifers are contaminated with coliform bacteria year-round, with relatively low concentrations in the dry season. However, in the rainy season, coliform bacteria and E. coli increase dramatically with extreme peaks at the beginning of the rainy season[24]. Bacteria are one of the most sensitive factors in the environment. Livestock manure and household waste are the main factors causing water pollution in karst areas[25.] Coliform and Enterococcus bacteria are known to interfere with health and even become an outbreak in an area. A suspected cholera outbreak in Sembale village, Kampala City, Uganda, in January 2019 suggested that the disease originated from the ingestion of drinking water from contaminated wells. This was caused by the breakdown of the Regional Drinking Water Company one month before the outbreak, which forced residents to consume water from wells, which turned out to have a coliform amount of > 900/100 ml[26]. Coliform bacteria's pathogenesis mechanism is carried out through several stages like other pathogenic bacteria. These stages are colonization at a certain point in the cell part of the intestinal surface (mucosal cells), cell division, destruction of intestinal cells, crossing intestinal cells and entering the bloodstream, tethering to target organs, and causing organ damage. Most pathogenic E. coli strains damage external host cells, but EIEC is an intracellular pathogen capable of invading and replicating inside intestinal mucosal cells and macrophages[27.]

Attachment of E. coli to the surface of the intestinal mucosa is done using pilus (or pili if there are many of them). Pili is a bulge of the bacterial cell wall whose antigens are called fimbriae antigens. Each type of E. coli has a unique fimbriae structure that varies in size and function and is encoded by different virulence genes. This causes a mechanism that varies in each group of pathogenic E. coli as a cause of damage to host cells. The pathogenic properties of E. coli are grouped into several types based on the mechanism of pathogenicity, virulence, and clinical syndrome caused[28].

Microbial research on water was also carried out in other Kars areas. For example, the microbiological characteristics of six karst springs from rural Apuseni Mountains, Romania (2022) tested exceeded the maximum limits set by WHO and European Directive 98/93/EC. Quantitative microbial risk assessments calculated for pathogenic E. coli show a high risk of infection per day and a high likelihood of disease in waters contaminated with these bacteria. Local communities also use these unprotected karst waters without treatment or quality evaluation. Microbiological analysis shows high levels of fecal contamination that can pose serious health risks to consumers[22]

The findings of this study were followed up by doing calculations using the QMRA method. QMRA, a process that allows quantitative assessment to estimate infection and disease risk from pathogenic microorganisms, has been widely applied in evaluating water and food[21] . The results of calculating the risk of QMRA infection are also presented in Table 4. Which shows the probability of infection and the annual probability of pathogenic bacterial infection in springs in the Banggai Karst Area of the Islands, Central Sulawesi, from four sampled springs, there is one sample with the highest probability of infection (Pinf) of 3.92 x10-4, namely Coliform bacteria in Lalomo springs. Furthermore, in the annual chance of infection (Pinf / year) Table 5, the highest pathogenic bacteria were also found in Lalomo spring samples, namely in coliform bacteria with the same value (Pinf / year) = 1.32×10-1. However, examination of other bacteria also showed that all positive springs contained coliform bacteria and Enterococcus exceeding the specified limit (1x10-4). The pill/year is the annual probability of disease developing in a population and the probability of developing disease after infection, i.e., morbidity[29]

According to the World Health Organization (WHO), the acceptable risk of infection in drinking water is <10−4/person/year. The United States Environmental Protection Agency has established appropriate surface water treatment systems standards. Similarly, as the World Health Organization recommended, the Netherlands also applies the same regulations to drinking water[30]. Meanwhile, the results of the QMRA analysis are evaluated within the framework of safety levels applied by the United States Environmental Protection Agency (US EPA), which stipulates that the estimated average annual risk should be below the value of 1 disease per 10,000 people exposed per year equivalent to the maximum allowable average daily risk of 2.7 × 10-7 for pathogens evaluated, regardless of their source, thus ensuring public health[17].

Table 7 presents possible health risks to drinking springs in the Banggai Karst Archipelago, Central Sulawesi. Of the four samples from various types of bacteria, it is known that all water samples have a high risk even though they are different types of bacteria. The results of this study are worth following up, considering that a report issued by the WHO shows that contaminated drinking water is responsible for about 80% of diseases worldwide and one-third of deaths in developing countries[31-37].

## RESEARCH LIMITATIONS

This study assesses public health risks to drinking water sources that may occur due to bacteriological exposure, such as Total Coliform, E. coli, Enterococcus, Staphylococcus, and Pseudomonas. The limitations of this study are:

1. This study only examines intake in the body through groundwater consumed; other sources of bacterial exposure, such as consumption of food as other agricultural products at the site or other sources of exposure containing bacteria, are not taken into account, so the effect estimated in the study may be more significant as the effect of bacterial accumulation from other sources.
2. This research data is only based on the results of one measurement, without considering changes in concentration before and after the study was conducted.

## CONCLUSION

Protecting catchment areas at springs in the Banggai Islands Karst Area from pathogenic bacterial contamination must be realized by Banggai Islands Regional Government Regulations to protect the community from health risks. The four springs are positive for containing various Coliform and Enterococcus bacteria that have exceeded the threshold. Of the four springs, there is one sample with the highest probability of infection (Pinf) in Lalomo Springs that can be detrimental to health. Risk management is needed to control risk factors that can cause health problems due to consuming and utilizing springs as a source of drinking water containing pathogenic bacteria.

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