Risk Assessment of *Escherichia coli* Exposure in Food Using QMRA and ISM Approaches at Polewali Mandar Hospital

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***Abstract*—This study evaluates the risk of *Escherichia coli* exposure in hospital food using the Quantitative Microbial Risk Assessment (QMRA) and Interpretive Structural Modeling (ISM) approaches. The QMRA method was used to identify hazards, assess exposure levels, and characterize the risks associated with *Escherichia coli*. The results showed that of the 5 food samples tested, one sample, Gogos, was detected positive for *Escherichia coli* with a colony count of 1.2×10^3 colonies/g, exceeding the established quality standard limit. The highest daily Probability of infection ($P_{inf/day}$) was recorded in Gogos at 2.52×10^{-1}, with an annual probability of infection reaching 1 (100%), indicating a high risk. The ISM serves to analyze the relationship between various risk factors that contribute to contamination. In this method, the sample consisted of 225 respondents, who were selected cross-sectionally from a total of 345 hospital staff, and it was found that key factors in contamination prevention include: hand washing, use of clean water, and checking expiration dates. These findings emphasize the importance of implementing strict hygiene practices in food management in Hospitals to reduce the risk of infection and improve food safety. This study is expected to provide valuable insights for decision makers in formulating better public health policies in the hospital environment.**

***Keywords*—*Escherichia coli*, microbiological risks, food management, food contamination, prevention strategies**

I. Introduction

Understanding the risk of exposure to *Escherichia coli* in food is essential for developing effective prevention and detection strategies [1–3]. *Escherichia coli* (*E. coli*), particularly strains such as O157:H7, is a pathogen responsible for foodborne illness globally and can cause a variety of health problems, ranging from diarrhea to severe complications such as Hemolytic Uremic Syndrome (HUS) [2–4]. Due to its ability to form biofilms, *Escherichia coli* O157:H7 [5] is able to survive in the food environment and increase the risk of contamination [6], potentially causing serious disease outbreaks [7].

Studies show that *E. coli* contamination is closely linked to inadequate hygiene during food handling, storage, or processing during the food handling, storage, or serving process. These practices are of particular concern in healthcare facilities such as hospitals, where populations susceptible to infection are particularly high. Research in South India shows the importance of surveillance of *E. coli* bacteria in snack foods, as they risk causing serious infections and carry potentially dangerous pathogens in humans [8, 9]. In the United States, cases of food contamination showed an association between inadequate sanitation and increased risk of *E. coli* infection [10]. Studies in Bangladesh reported that 55.1% of food samples from campus cafeterias were contaminated with *E. coli* [11, 12], emphasizing the need for a robust food safety system. In Kenya, a similar study found high contamination of food and water sold in public eating places, indicating the global spread of this threat [6]. This further emphasizes that food safety is a transnational and contextual issue, including in hospitals.

Safety practices in South India, particularly concerning *Escherichia coli* bacteria in snack food samples, are important due to the potential for serious infections [13] and the potential for dangerous pathogens in humans [12]. The prevalence of *Escherichia coli* in food generally indicates inadequate hygiene practices during handling, preparation, and storage. Therefore, it is important to implement strict hygiene protocols [13]. Studies in various regions, including the United States [14] and Bangladesh [15], have reported cases of *Escherichia coli* associated with contaminated food consumption, emphasizing the importance of food safety in various contexts, including hospitals.

In food risk management, the Quantitative Microbiological Risk Assessment (QMRA) approach has become an important tool to identify microbiological hazards, estimate exposure, and characterize risk [6]. QMRA provides a quantitative framework for describing the transmission of pathogenic microorganisms from food to humans. However, there is significant heterogeneity in its application across different sectors, and its use in hospital settings is limited [16]. In addition, QMRA results tend to focus on laboratory data without examining the complexity of systemic contamination-causing factors.

To complement QMRA, the Interpretative Structural Modeling (ISM) approach can be used to analyze and map the relationships between various risk factors affecting food contamination [17, 18]. ISM helps to hierarchize and structure the relationships between variables, thereby identifying the most strategic intervention points in the food system. Several studies have shown that ISM is effective in

developing food safety strategies by considering the interdependencies between risk factors, including in the context of sanitation, food handler behavior, and food processing [19].

However, there are still limited studies that integrate QMRA and ISM methods in the context of food safety in hospitals. This integrative approach can provide a more thorough understanding, both quantitatively and structurally, of the risk of microbial contamination such as *E. coli*. Therefore, it is important to explore combining these 2 approaches as a strategic effort in improving food risk control.

This study aims to evaluate the risk of *Escherichia coli* exposure in food served to staff at Regional Public Hospital (RSUD) Hajjah Andi Depu, Polewali Mandar Regency using the QMRA method, as well as analyzing the relationship of contamination risk factors with the ISM approach. The novelty of this research lies in the integration of the 2 approaches in one study, which has not been widely applied in the hospital context. This methodology not only quantitatively calculates the potential risk of infection, but also prioritizes strategic interventions based on the structure of the relationship between risk factors. The results are expected to serve as a basis for decision-making in hospital food safety policy and enrich the scientific literature in the field of microbiological risk management.

II. Literature Review

These studies illustrate the growing recognition of QMRA as an important component in food safety risk management. In addition, the integration of Interpretative Structural Modelling (ISM) with QMRA has been explored to better understand the reciprocal relationships among various risk factors. However, reference is given to the application of ISM. In recent years, the Quantitative Microbial Risk Evaluation Approach (QMRA) has become an important component of food safety risk management. QMRA provides a systematic framework for evaluating microbiological risks associated with food consumption and has been used by various industries to improve food safety.

Previous research reviews on QMRA and its integration with ISM in food safety risk management, however, lacked a critical synthesis linking previous findings to the current research design and hypotheses. Previous research demonstrated the importance of QMRA in systematically evaluating microbiological risks and began to explore the relationships between risk factors through ISM [6].

This study addresses a critical gap by evaluating *Escherichia coli* contamination risk in food consumed by healthcare staff, an area that has been underexplored in prior studies. By integrating Quantitative Microbial Risk Assessment (QMRA) with Interpretative Structural Modelling (ISM), the study enables a more detailed and data-driven understanding of contributing factors such as food handler hygiene, leading to more precise recommendations for food safety interventions in hospital environments [7].

In bibliometric studies to see novelty in research studies, the use of keyword analysis and citation networks is also one of the best ways. Fig. 1 lists keywords with novelty or appearance starting in 2021, some of which are: *Escherichia coli* O157:H7 (2021.89); anti-bacterial agents (2021.64); risk analysis (2021.80); food (2021.50). From these keywords, several possible research directions are being explored further, including:

(a) Risk analysis of *E. coli* contamination in the food supply chain.

(b) Development of a disease spread prediction model.

(c) Development of food processing technologies to reduce the risk of *E. coli* contamination.

(d) Development of detection and identification methods for *Escherichia coli* O157:H7.

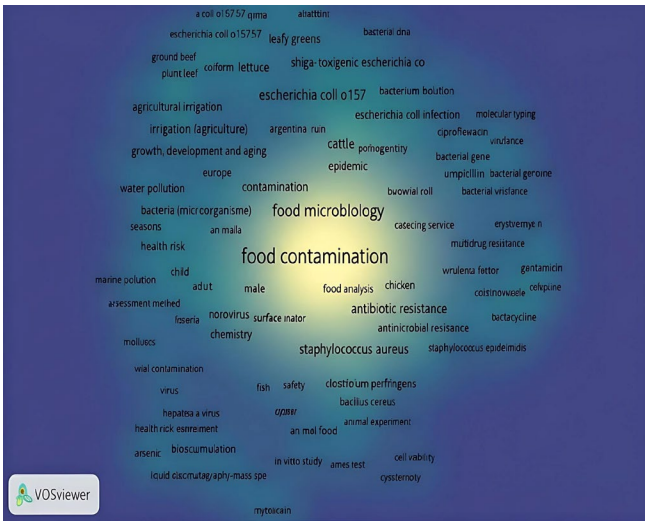


Fig. 1. Density visualization.

When viewed from Fig. 1, it shows that topics related to food contamination are still widely discussed. Scientific mapping highlights the need to explore *Escherichia coli* risk assessment in food consumed by hospital staff more deeply.

A network visualization showing the relationships between terms related to food safety and risk management, with nodes representing terms and edges showing the relationships between them. Nodes are grouped based on semantic similarity, with blue groups focusing on food safety and microbiology, green groups on risk assessment and management, red groups possibly related to regulation, and yellow groups related to production. Central terms such as "risk assessment" and "risk management" play an important role in linking the various concepts, reflecting the complexity and interconnectedness of factors that need to be considered in food safety.

As shown in Fig. 2, the conceptual map generated from bibliometric network analysis illustrates the co-occurrence and relationships among key terms related to food risk and safety assessment. The visualization highlights "risk assessment" as a central node, strongly connected with themes such as food safety, food microbiology, risk management, and exposure assessment. The clustering of terms reflects major research domains, including microbiological hazards, regulatory aspects, and consumer risk, indicating the multidisciplinary nature of food safety research. Furthermore, Fig. 3 presents a concept mapping of food safety risk assessment based on bibliometric network analysis. The visualization shows distinct thematic clusters representing major research domains, including food safety and microbiology, risk assessment and risk management,

regulatory and monitoring aspects, and toxicological studies. The central position of "risk assessment" indicates its integrative role in linking microbiological hazards, exposure analysis, and management strategies, reflecting the interconnected nature of concepts involved in food safety risk assessment.

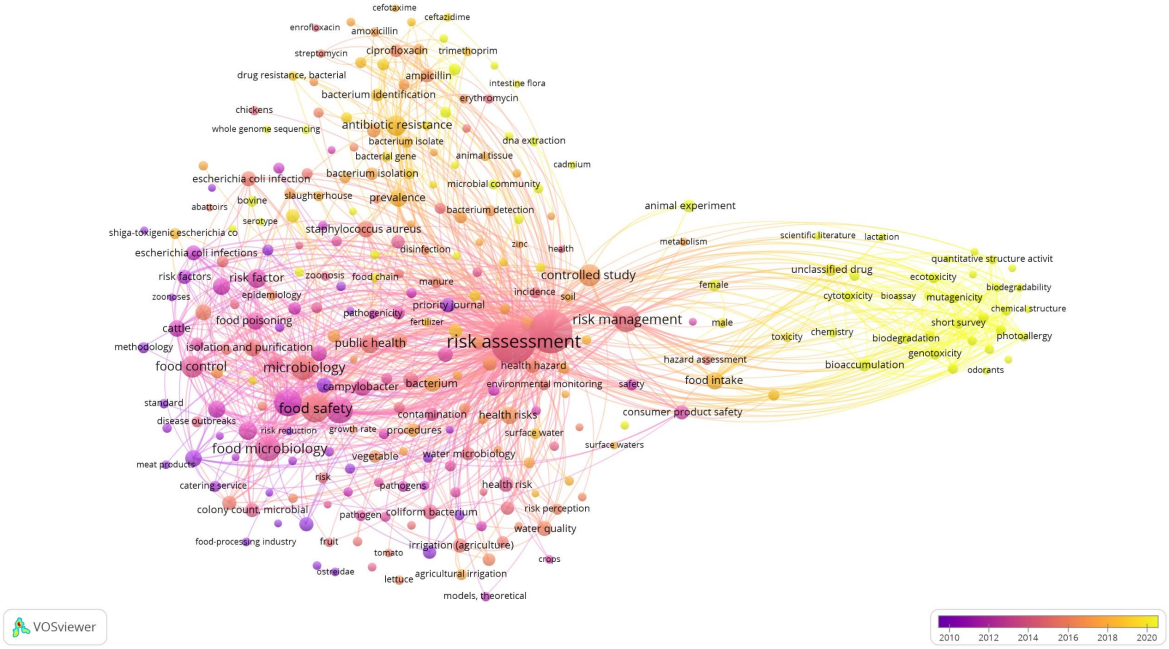


Fig. 2. Conceptual map: Food risk and safety assessment.

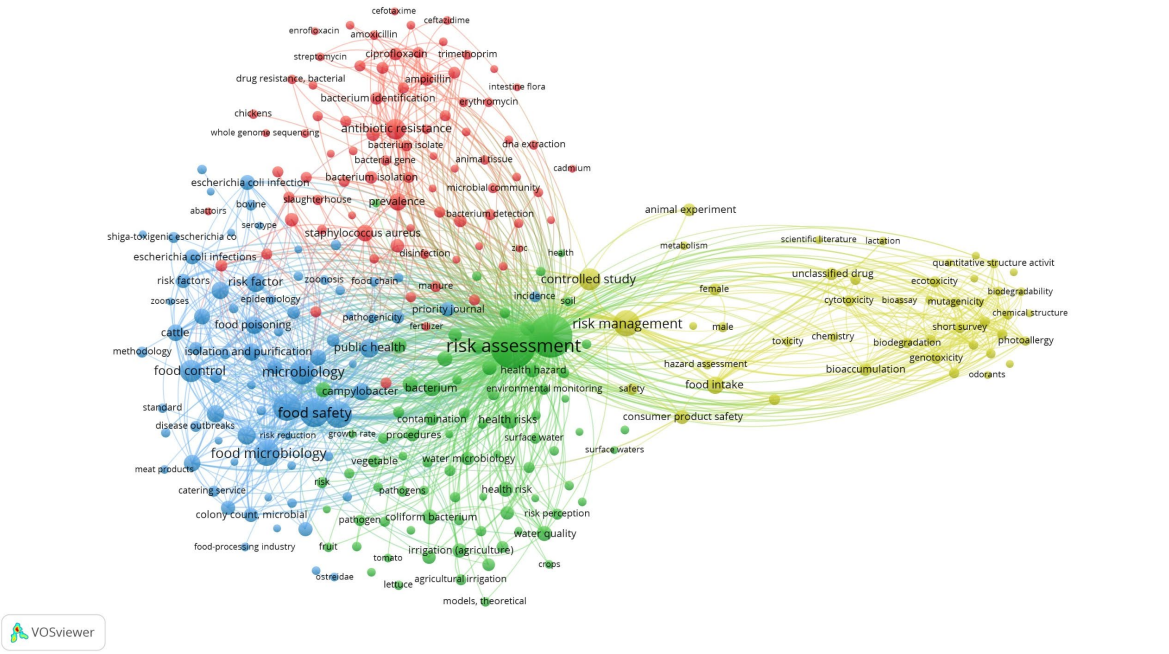


Fig. 3. Concept mapping in food safety risk assessment.

These conceptual relationships underline the relevance of quantitative approaches, such as QMRA, in addressing complex food safety risks. Recent studies have highlighted the importance of integrating QMRA to improve risk assessment. This integration enables the identification of key pathogen traits that influence risk, which is important for developing effective food safety interventions. In addition, the role of food handlers is closely related to the presence of *Escherichia coli* [8]. Contributing to *Escherichia coli* contamination in food is poor personal hygiene among food handlers, which is the main factor contributing to *Escherichia coli* in food [9].

Table 1 summarizes a series of recent studies (from 2020 to 2025) on microbial contamination in various food products. Broadly speaking, these studies identify various types of pathogens such as *Escherichia coli* O157:H7, salmonella, campylobacter, stec, and vibrio parahaemolyticus, which originate from various sources ranging from imported beef and animals, dairy products, to shellfish from coastal waters. To detect and assess these contamination risks, researchers used advanced methods such as simulation-based Quantitative Microbial Risk Assessment (QMRA), Whole Genome Sequencing (WGS) for deeper data integration, and nanobody-based immunoassay and Polymerase Chain Reaction (PCR) techniques capable of detecting contaminants at very low concentrations.

Table 1. Trends in microbiological risk assessment: A review of recent studies

Ref. &Year	Type of Food	Type of Contamination	Source of Contamination	Detection Method	Sample Size	Study Site and Population	Population	Key Findings
[10] 2020	Beef (particularly imports from the USA)	*Escherichia coli* O157:H7	Raw beef imported from the USA	Quantitative Microbial Risk Assessment (QMRA), simulation based on contamination data from the United States Department of Agriculture (USDA)and consumption patterns in Taiwan	Contamination data from USDA (1995–2012), consumption data from the health and nutrition survey in Taiwan (2005–2012)	Taiwan	Taiwanese population by age and gender	Proper cooking of beef can significantly reduce the risk of foodborne illness to almost zero.
[6] 2023	Various (Lm, Salmonella, Campylobacter, STEC)	Pathogenic microorganisms (bacteria)	Animals and food	Whole Genome Sequencing (WGS), Random Forest, Swift Quantitative Microbiological Risk Assessment (sQMRA)	Not explicitly stated, but data from multiple studies were used.	Netherlands (primarily), data from other locations used for comparison	Humans are consuming contaminated food.	Incorporating WGS data into QMRA enhances risk estimates, linking Listeria monocytogenes virulence to symptoms and genotypes.
[8] 2025	Beef, Milk, Orange Juice	*Bakteri Escherichia coli* O157:H7	Meat and dairy products	Nanobody-based sandwich immunoassay, Enzyme-Linked Immunosorbent Assay (ELISA), real-time Polymerase Chain Reaction (PCR)	Samples were spiked with 5 Colony-Forming Units (CFU)of *Escherichia coli* O157:H7, and analyses were performed at various incubation times.	Analysis of food samples from the market	Contaminated food samples	The nanobody-based immunoassay can detect *Escherichia coli* O157:H7 at concentrations as low as 5 CFU/25 mg or 5 CFU/200 mL.
[11] 2022	Shellfish oysters, clams, mussels, scallops)	*Vibrio parahaemolyticus*	Shellfish harvested from coastal waters	Quantitative Microbial Risk Assessment (QMRA), PCR assays for pathogenicity determination	864 samples of shellfish	Coastal cities in Eastern China	The general public consuming shellfish	62.73% of shellfish samples tested positive for V. parahaemolyticus, with an annual illness probability of 3.49×10^{-5}, higher in summer and autumn.

These studies were conducted in various geographical locations, including Taiwan, the Netherlands, and coastal regions of China, highlighting that food safety is a global issue that requires serious attention. Key findings from these studies provide important insights for risk mitigation; for example, studies show that cooking beef properly can significantly reduce the risk of foodborne illness. Furthermore, the integration of WGS data improves the accuracy of pathogen risk estimates, and early detection methods such as nanobody immunoassays show great potential for rapid intervention. The finding of seasonal contamination in shellfish also underscores the need for adaptive surveillance and prevention strategies.

III. Materials and Methods

A. Study Design

This study was conducted at Hajjah Andi Depu Hospital, Polewali Mandar City, a major healthcare facility where staff play key roles in food safety management. Out of a total of 345 employees, 225 were purposively selected, particularly those working morning to evening shifts to ensure representativeness of roles related to food safety management.

This research is an analytical survey study with a cross-sectional approach using the Quantitative Microbial Risk Assessment (QMRA) and Interpretative Structural Modeling (ISM) methods. The cross-sectional approach was chosen because it allows data collection at one specific point in time to provide a clear picture of contamination points [12], and risk factors associated with *Escherichia coli* exposure in food served to hospital staff.

Food sampling utilized a randomized, cross-sectional strategy across a range of processed and ready-to-eat foods routinely consumed by staff aged 18 years and above within the hospital setting at the time of data collection. Inclusion criteria included foods routinely consumed by staff, while exclusion criteria eliminated uncommonly consumed foods and packaged or processed foods originating from outside the hospital, to maintain the validity and representativeness of the risk assessment.

Testing was conducted on 5 key food samples selected based on the highest frequency of consumption and the most relevant potential contamination risks in the hospital environment. This restriction on the number of samples was due to limited laboratory resources and the need to maintain optimal quality and integrity of the microbiological testing. Despite the limited number of samples, selection based on representative criteria is expected to provide a significant picture of the risk of exposure to *Escherichia coli* in food consumed by staff.

Sample testing was carried out in the laboratory of the Makassar Health Laboratory Centre (BBLK) with strict handling and storage procedures to maintain the microbiological integrity of the samples until testing. The QMRA methodology is carried out through several stages, from hazard identification, dose-response analysis, to risk characterization, to produce quantitative calculations related to potential health risks due to the consumption of contaminated food.

While the purposive sample selection and limited sample size provided a focus on specific factors, it also brought limitations regarding the statistical power and generalization capacity of the results[13]. Therefore, the results of this study should be interpreted with caution, and further research with a more robust design and larger sample size is recommended to validate and extend these findings.

B. Data Analysis

Based on the results of laboratory examinations and interviews conducted through the QMRA method through a systematic approach that combines the principles of risk assessment to determine the possibility of infection or disease due to exposure to pathogenic microorganisms, and Interpretive Structural Modeling (ISM) Analysis.

The expert responses were analyzed with ISM through the creation of a Structural Self-Interaction Matrix (SSIM), which was transformed into a Final Reachability Matrix to identify direct and indirect relationships between sub-elements. From this final matrix, the Driver Power and Dependence of each sub-element were calculated, which were then visualized in a directional graph and hierarchical level structure.

C. Hazard Identification

At this stage, pathogenic microorganisms that can harm health are identified. This process includes identifying organisms, such as *Escherichia coli*, that are present in food and their properties that can cause disease.

D. Exposure Assessment

This step evaluates the likelihood of individual exposure to pathogenic microorganisms through food. The data collected included the level of bacterial contamination in food, the quantity of food consumed, and the frequency of exposure within the population. After obtaining these values, the calculation of microbial risk analysis proceeds using Eq. (1).

$$P_{inf} = E \times \gamma \; or \; \left(P_{inf}\right) = 1 - \left(1 + \frac{d}{\beta}\right)^{-a} \quad (1)$$

where P_{inf} means probability of infection; E means exposure constant or factor; γ means gamma function or relevant function; d means dose or exposure level; β means scale parameter; a means shape parameter.

Furthermore, the calculation of disease risk per year in individuals is carried out using Eq. (2).

$$P_{Annual} = 1 - \left(1 - P_{daily}\right)^{365} \quad (2)$$

where P_{Annual} means annual Probability of infection (0–1); P_{daily} means daily probability of infection (0–1); 365 is the number of days in 1 year.

E. Dose-Response Analysis

The relationship between the number of bacteria exposed and the likelihood of infection or disease is examined at this stage. This analysis uses epidemiological data or laboratory tests that show the human body's reaction to exposure to various microorganisms. Poisson Dose-Response (DR) β values and β-binomial DR have been widely used in describing dose-response for risk assessment. The beta-Poisson dose-response model, chosen for its

effectiveness in describing the probability of *Escherichia coli* infection based on the ingested dose, uses parameters $\alpha = 0.1778$ and $\beta = 1.78 \times 10^{-6}$ [14].

$$P_{inf/day} = 1 - 1 + \frac{d^{-\alpha}}{\beta}$$

where $P_{inf/day}$ represents the probability of infection per day, d means the dose of pathogenic infection; α and β means parameter distribution beta *Escherichia coli* ($\alpha = 0.1778$ and $\beta = 1.78 \times 10^{-6}$) [16].

F. Risk Characterization

This final step integrates all data from the previous stages to provide a comprehensive overview of health risks. Exposure to foodborne microorganisms may cause infections, varying disease severity, and adverse health effects. The risk associated with this disease is calculated using the following formula. The probability of infection was calculated using Eq. (3) as follows.

$$Disease\ Risk\ (P_{III}) = P_{Infections/year} \times P_{III/inf} \quad (3)$$

where, $Disease\ Risk\ (P_{III})$means annual disease risk arising from exposure to pathogenic microorganisms from food or the environment, $P_{Infections/year}$ means the probability of severe disease (adverse health effects) after an individual is infected, $P_{III/inf}$ means annual probability of infection.

Through these 4 steps, QMRA can provide an accurate estimate of the risk of infection from consuming food contaminated with pathogenic microorganisms. It serves as it is the basis for decision-making in risk management and food safety policies.

The process of Quantitative Microbial Risk Assessment (QMRA) is illustrated in Fig. 4, which outlines the hazard identification, exposure assessment, and dose-response modeling.

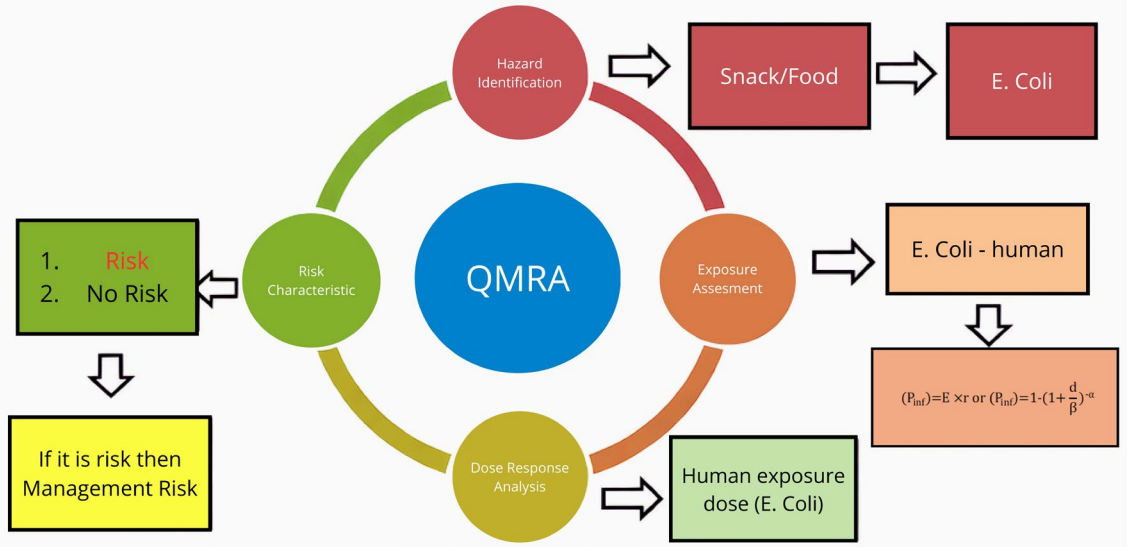


Fig. 4. QMRA method.

G. Interpretive Structural Modeling Analysis

Interpretive Structural Modeling (ISM) is a powerful methodology for analyzing complex systems by identifying relationships between various factors. ISM was introduced by Warfield in 1973 and has since been applied in various fields such as technology, sustainability, and entrepreneurship. ISM works by steps such as identifying the problem, determining the influential factors, developing a matrix of relationships between those factors, and analyzing the matrix to map the structure of the relationships in the form of an easy-to-understand visual map. ISM thus aids decision-making in complex situations through the visualization and clarification of relationships between elements [18, 19].

The results from the ISM model validation were then used to prioritize interventions and develop targeted strategies for food contamination control in hospital environments. The ISM analysis was conducted with clear methodology: sub-elements were systematically selected based on input from a multidisciplinary expert panel, including microbiologists, food safety experts, and field practitioners. Consensus was built using the Delphi method, ensuring unbiased and iterative agreement. Model validation followed standard ISM procedures with reachability matrix and transitivity checks to confirm the logical structure. This approach aligns with recent best practices in ISM and expert consensus, enhancing transparency and rigor in the model [17]. Therefore, the ISM technique is used to find the most influential challenges and obtain contextual relationships between challenges. The steps required for the ISM tool application are given below [18].

1) Stage I: Determination of elements

- Step 1: 10 different challenges are used to apply the ISM tool.
- Step 2: A detailed relation is obtained between the challenges, and the Structural Self-Interaction Matrix (SSIM) is constructed based on the relationship in terms of V, A, X, and O.
- Step 3: This SSIM matrix is converted into binary forms (0 and 1), and an initial reachability matrix is found.
- Step 4: A transitivity check of the initial reachability matrix is performed.
- Step 5: Level segmentation is performed on the final reachability matrix.

- Step 6: A hierarchical structure is framed based on the level partition, which shows the type of relationship among challenges.

The demographic characteristics of the respondents are summarized in Table 2.

Table 2. Sub-elements of food contamination prevention strategy at Hajjah Andi Depu Hospital

Code	Sub-Elements
A1	Wash your hands before handling food
A2	Using separators for raw and cooked food
A3	Checking the expiration date of food products
A4	Storing food at the right temperature
A5	Cleaning kitchen surfaces before and after cooking
A6	Using gloves when handling food
A7	Keep cooking and dining utensils clean
A8	Avoid contact between raw and cooked foods
A9	Using clean water for cooking and washing food
A10	Ensure food cooking temperatures reach safe standards

2) Stage II: Structural Self-Interaction Matrix (SSIM)

The responses from experts are presented in the form of a matrix that depicts the relationships between the sub-elements. The responses were then combined, and the frequency was calculated to infer how often the elements interacted with each other. There are 4 standard symbols used to describe the relationship between sub-elements.

V: Sub-element *i* affects sub-element *j*.
A: Sub-element *j* affects sub-element *i*.
X: Sub-elements *i* and *j* influence each other.
O: Sub-elements *i* and *j* are not related.

3) Stage III: Affordability Matrix (Risk Management (RM))

The affordability matrix develops a Structural Self-Interaction Matrix (SSIM) that is based on the relationships between the selected criteria. At this stage, SSIM is converted into a binary matrix (affordability matrix). The V, A, X, and O symbols in SSIM are replaced with binary numbers 1 and 0.

- If the relationship (i, j) in SSIM is V, then the relationship (i, j) in the affordability matrix becomes 1, while (j, i) is 0.
- If the relationship (i, j) in SSIM is A, then the relationship (i, j) in the affordability matrix becomes 0, and (j, i) is 1.
- If the relationship (i, j) in SSIM is X, then the relationship (i, j) in the affordability matrix becomes 1, and (j, i) is also 1.
- If the relationship (i, j) in SSIM is O, then the relationship (i, j) in the affordability matrix becomes 0, and (j, i) is also 0.

H. Research Ethics Approval

This research has undergone an ethical approval process, and the results of the ethical approval recommendation, number 582/UN4.14.1/TP.01.02/2024, dated February 18, 2024, indicate that the protocol and associated documents have received approval from the Chairman and the Secretary of the Research Ethics Commission at Hasanuddin University.

IV. Result and Discussion

A. Result

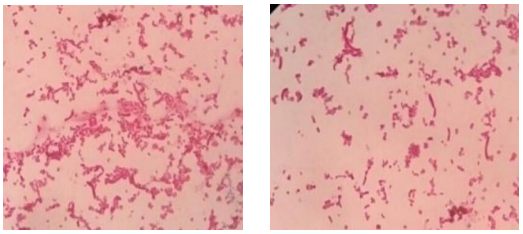
The infographic describes the purpose of the study that analyzed the health risks of exposure to *Escherichia coli* in food using QMRA, emphasizing the importance of food safety, an important context about food hazards in hospital settings. This image provides a clear picture of the health risks associated with *Escherichia coli* in food consumed by hospital staff, and the importance of food safety testing and management to protect health.

Fig. 5. Infographic summarizing the risk assessment of *Escherichia coli* exposure in hospital food using the QMRA and ISM approaches.

An infographic summarizing the risk of *Escherichia coli* exposure in hospital food using QMRA and ISM is presented in Fig. 5.

Fig. 6(a) shows *Escherichia coli* cells that have been stained using the Gram stain method. In this image, the cells appear pink in color, indicating that *Escherichia coli* is a Gram-negative bacterium, and Fig. 6(b) also shows *Escherichia coli* cells with similar characteristics, reinforcing

the results of the biochemical tests performed. These 2 images provide important visualizations in the identification and analysis of microorganisms, especially in the context of research on pathogens that can cause disease in humans. Gram staining is a basic technique in microbiology that is profound in the classification of bacteria based on the nature of their cell wall.



(a) (b)

Fig. 6. Biochemical and microscopic analysis of *E. coli*. (a). *E.Coli* reaction biochemical test results. (b) Gram stain results *E. coli* microscopy.

Table 3 shows that of the 5 food samples examined, there was one food sample that was positive for *Escherichia coli* bacteria and exceeded the established quality standards, namely the Gogos food sample with a colony count of 1.2×10^3. In quantitative risk analysis, food pathogen Exposure (E) was described in Eq. (4).

$$E = CR \times (1 - P) \quad (4)$$

where E means average exposure to bacteria per gram of food; CR means experimentally measured *E. coli* contamination level (colonies/g); and P means the effectiveness factor of the food processing process. In the example given, the value of P is 0.99, which means there is a 99% reduction in the contamination level after processing (PT: food processing, 99% reduction using the effectiveness factor).

Table 3. Distribution rate of *Escherichia coli* colonies across different food samples

Type of Food	*E.Coli* Test Result (Colonies/g)	Quality standard
Jeli	$<1.0 \times 10^1$	score 0
Mini Martabak	$<1.0 \times 10^1$	score 0
Gogos	1.2×10^3	score 0
Sambusa	$<1.0 \times 10^1$	score 0
Roti Pawa	$<1.0 \times 10^1$	score 0

Source: Primary Data, 2024

As shown in Table 4, the average distribution of *Escherichia coli* among food types reveals that exposure to *Escherichia coli* pathogens from food samples is highest for the type of food gogos at 1000, while the average exposure to *Escherichia coli* pathogens from food samples is lowest for the type of food pawa bread at 250.

Table 4. Distribution of mean exposure to *Escherichia coli* bacteria

Type of Food	Distribution of Mean Exposure to *Escherichia coli*
Jeli	300
Mini Martabak	300
Gogos	1000
Sambusa	100
Roti Pawa	250

This table shows the average values of exposure levels of *Escherichia coli* bacteria in different foods. The numbers illustrate how much of the bacteria is found in different foods. These values are quantitative and are usually measured in the number of bacterial colonies per unit (which has not been specified in the table). This data is important as an indicator of contamination and potential direct exposure of food to *Escherichia coli* bacteria.

Table 5. Distribution analysis of the probability of infection (P_{inf})

Type of Food	$P_{inf/day}$ *Escherichia coli*
Jeli	2.41×10^{-1}
Mini Martabak	2.13×10^{-1}
Gogos	2.52×10^{-1}
Sambusa	1.76×10^{-1}
Roti Pawa	2.07×10^{-1}

The results of the QMRA are also presented in Table 5, which indicates the chance of infection and the daily chance of infection of pathogenic bacteria in food samples. Of the 5 food samples, there is one sample has the highest chance of infection (P_{inf}) highest retrieved from 2.52×10^{-1}, namely *Escherichia coli* bacteria in the Gogos food sample.

The presentation of this table is important as it provides concrete data on the level of exposure to *Escherichia coli* bacteria in different types of food as well as the resulting risk of infection. The table not only presents bacterial exposure values but also calculates clinical and epidemiological probabilities of infection, thus providing a comprehensive picture of potential health hazards. These data form the basis for further risk analyses and effective food contamination mitigation decisions, thus strengthening the validity of the research results while supporting efforts to improve food safety.

Table 6. Infection probability distribution/analysis year

Type of Food	$P_{inf/day}$ *Escherichia coli*	Pil *Escherichia coli*	$P_{inf/year}$ *Escherichia coli*
Jeli	1	2.13×10^{-1}	High Risk
Mini Martabak	1	2.13×10^{-1}	High Risk
Gogos	1	2.52×10^{-1}	High Risk
Sambusa	1	1.76×10^{-1}	High Risk
Roti Pawa	1	2.07×10^{-1}	High Risk

Table 6 shows the annual likelihood of *Escherichia coli* infection in the different food types analyzed. 2 main columns appear: Food Type, which includes Jeli, Mini Martabak, Gogos, Sambusa, and Roti Pawa. Infection Probability ($P_{inf/years}$), which shows the annual probability of infection values for each food type, with all values indicating infection. All of the food types listed have a probability of infection every year. This indicates that customers could be exposed to significant *Escherichia coli* infections from these foods.

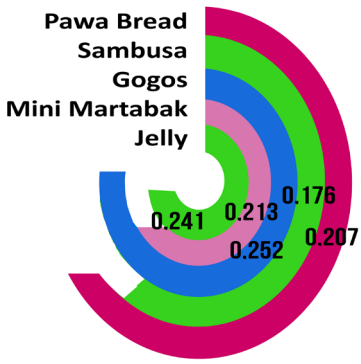


Fig. 7. Mean distribution of dose-response analysis.

These values indicate that the likelihood of infection for all

food types is the same, with the highest values for Gogos. This suggests that these foods may be more easily contaminated. As all food types show significant hazards, managers should take stricter precautions to ensure food safety and protect patients, hospitals, and staff.

Fig. 7 shows the results of the dose-response analysis distribution for the average respondent. *Escherichia coli* bacteria dominated this analysis as they produced a significant dose-response based on calculations on food samples (Gogos).

B. Results of Quantitative Analysis (Interpretive Structural Modelling Analysis)

The strategic elements of food contamination prevention practices at RSUD Hajjah Andi Depu were obtained through a process of in-depth interviews with experts and food hygiene managers at the hospital, and complemented by literature studies related to hygiene and food safety in the hospital environment. The determination of strategy sub-elements was adjusted to the results of the identification of food contamination risks and analysis of preventive practices that have been implemented at RSUD Hajjah Andi Depu. The sub-elements of the strategy for food contamination prevention practices at RSUD Hajjah Andi Depu are as follows.

Table 7. Sub-elements of food contamination prevention strategy at Hajjah Andi Depu Hospital

Code	Sub-Element
A1	Washing hands before handling food
A2	Using separators for raw and cooked food
A3	Checking the expiration date of food products
A4	Storing food at the right temperature
A5	Cleaning kitchen surfaces before and after cooking
A6	Using gloves when handling food
A7	Keeping cooking and dining utensils clean
A8	Avoid contact between raw and cooked foods.
A9	Using clean water for cooking and washing food
A10	Ensure food cooking temperatures reach safe standards.

The validation results shown in Table 7 indicate strong expert agreement on the structure and relevance of the ISM model, confirming its applicability for analyzing foodborne contamination risk in healthcare settings.

The SSIM was then converted into the Initial Reachability Matrix, which is shown in the final reachability matrix, using Visual Analytics Explanatory Organizer (VAXO). VAXO is a data visualization tool, to generate comprehensive network diagrams that clarify thematic research clusters. The letters in the matrix are then converted into numbers 1 and 0 according to Interpretative Structural Modeling (ISM) rules. After that, to see the direct and indirect influence between sub-elements, the Final Reachability Matrix is then processed again so that it fulfills the transitivity law.

Food contamination prevention practices at Hajjah Andi Depu Regional General Hospital were measured quantitatively using the Specific Survey Instrument for Microbiological (SSIM) method. The evaluation results are presented in Table 8, which shows the identification of practices (columns 1–10) and their implementation status. The symbol "V" means the practice is implemented, "X" means it is not yet implemented, and "O" means it is not relevant. The analysis shows that several key practices, especially those marked "X", still need to be improved. These findings form the basis for recommendations for improving hygiene and reducing the risk of food contamination at Hajjah Andi Depu Regional General Hospital.

Table 8. Matrix SSIM food contamination prevention practices at RSUD Hajjah Andi Depu

(*i*, *j*)	1	2	3	4	5	6	7	8	9	10
1		V	X	X	X	X	V	X	X	V
2			X	X	X	X	X	V	X	V
3				V	X	X	X	X	X	V
4					X	X	X	X	X	V
5						X	X	X	X	O
6							X	X	X	V
7								X	X	O
8									X	X
9										V
10										

After the transitivity rule is satisfied, driver power and dependence are calculated in the canonical matrix (Table 9) by summing the sub-element points horizontally for driver power and vertically for dependence. The highest driver power or dependence score is ranked first, while the lowest is ranked last. This ranking system is essential for visualizing the data through directional graphs and hierarchical level structures. One of the outcomes of Interpretive Structural Modeling (ISM) is a graph that categorizes requirement sub-elements into 4 quadrants: Quadrant I (Independent), Quadrant II (Linkage), Quadrant III (Dependent), and Quadrant IV (Autonomous). The linkage quadrant describes less stable relationships between variables, where actions on one sub-element will impact other sub-elements with feedback that magnify the effect, so it needs to be studied carefully. The dependent quadrant includes sub-elements that are bound by the influence of other elements. Point summation and ranking are useful for displaying data in the form of a directional graph and level structure, as shown in Table 10 and Fig. 8.

Table 9. Final reachability matrix food contamination prevention practices at RSUD Hajjah Andi Depu

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
A1	1	1	1	1	1	1	1	1	1	1
A2	0	1	1	1	1	1	1	1	1	1
A3	1	1	1	1	1	1	1	1	1	1
A4	1	1	0	1	1	1	1	1	1	1
A5	1	1	1	1	1	1	1	1	1	1
A6	1	1	1	1	1	1	1	1	1	1
A7	0	1	1	1	1	1	1	1	1	1
A8	1	0	1	1	1	1	1	1	1	1
A9	1	1	1	1	1	1	1	1	1	1
A10	0	0	0	0	0	0	0	1	0	1

After the transitivity rules are fulfilled, the driver power and dependence calculations contained in the Canonical Matrix (CM) are performed. The driver power value is calculated by summing the points of each element horizontally to the right, whereas the dependence value is determined by summing the points vertically downward. This Canonical Matrix is used as the basis for drawing the diagram that provides the first visual output of the hierarchical structure of food contamination prevention practice strategies at RSUD Hajjah Andi Depu, as described below.

Next is to compile the strategy hierarchy into a graph that divides the elements into quadrants and their coordinates. There are 4 quadrant positions consisting of quadrant I (independent), quadrant II (linkage), quadrant III (dependent), and quadrant IV (autonomous) [19].

Fig. 8 presents a visual analysis of 2 critical variables,

namely Driving Power and Dependence Power, which describe the dynamics of the relationship between elements in a system. Each point on the graph represents an analyzed element, identified by a specific code (A1 to A10). The horizontal axis, Dependence Power, reflects the degree of dependence of an element on other elements in the system, while the vertical axis, Driving Power, shows the degree of influence or ability of that element to influence other elements. The distribution of elements spread across the 4 quadrants of the graph provides strategic insights into the role of each element. Elements in the upper right quadrant indicate high influence and dependence, signifying a key role and strong interconnection with other elements. Conversely, elements in the upper left quadrant have high influence but low dependence, acting as independent driving forces. Elements in the lower right quadrant tend to be highly dependent on other elements with limited influence, while the lower left quadrant, if present, indicates elements with low influence and dependence. Understanding these positions and relationships is crucial for effective decision-making in system management and development to maximize the role of elements based on their differing levels of influence and dependence.

Table 10. Canonical matrix food contamination prevention practices food contamination prevention practices at RSUD Hajjah Andi Depu

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	DP	R	D	H
A1	1	1	1	1	1	1	1	1	1	1	10	1	7	4
A2	0	1	1	1	1	1	1	1	1	1	9	2	8	3
A3	1	1	1	1	1	1	1	1	1	1	10	1	8	3
A4	1	1	0	1	1	1	1	1	1	1	9	2	9	2
A5	1	1	1	1	1	1	1	1	1	1	10	1	9	2
A6	1	1	1	1	1	1	1	1	1	1	10	1	9	2
A7	0	1	1	1	1	1	1	1	1	1	9	2	9	2
A8	1	0	1	1	1	1	1	1	1	1	9	2	10	1
A9	1	1	1	1	1	1	1	1	1	1	10	1	9	2
A10	0	0	0	0	0	0	0	1	0	1	2	3	10	1

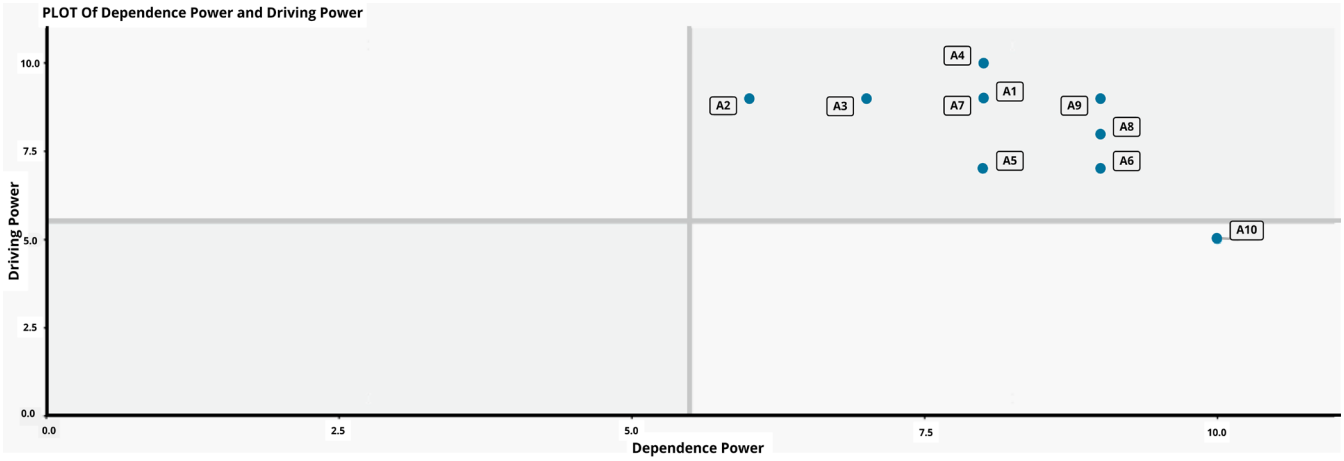


Fig. 8. Directional graph food contamination prevention practices.

Based on the results presented in Fig. 8, the level structure model is one of the outputs of the Interpretive Structural Modeling (ISM) method that can serve as a reference in identifying the expected strategies in efforts to prevent food contamination in hospitals. This study identifies 4 levels of prevention strategies, where the first-level strategy is a key element or sub-element of the strategy with the highest driver power. Conversely, the strategy at the fourth level is a sub-element of the strategy with the lowest driving power and has the highest dependence.

At the first level, key requirements include crucial practices such as washing hands before handling food, checking food expiration dates, cleaning kitchen surfaces before and after cooking, wearing gloves when handling food, and using clean water for cooking and washing food ingredients. These 5 practices are fundamental elements in implementing food contamination prevention strategies in hospital environments. Meanwhile, at the third level, ensuring that food is cooked at the appropriate temperature is a basic strategy in this hierarchical structure.

Personal hygiene reflects an individual's responsibility to maintain the health of both themselves and others. By washing hands regularly, we can eliminate germs and pathogens that may be present, thereby reducing the risk of initial contamination. In the context of Interpretative Structural Modelling (ISM), personal hygiene is a key element underlying the entire food safety management system. By fostering collective awareness among all team members regarding the importance of hygiene, we not only protect ourselves but also create a safer environment for everyone [19]. This underscores that each individual plays a vital role in upholding high food safety standards, which ultimately contribute to the overall health of the community. Control of *Escherichia coli* contamination in food can begin during the processing phase, specifically through cooking at high temperatures while also ensuring that the storage temperature of processed food is maintained before serving. Food should be placed in clean containers, and measures should be taken to avoid contamination from food handlers, flies, and the surrounding environment.

The diagram shown is a layered hierarchical structure consisting of 3 levels. Each level is represented by a circle of different colors, complete with a table inside.

- Level 1 (orange): Consists of elements A1, A3, A5, A6, and A9.
- Level 2 (green): Consists of elements A2, A4, A7, and A8.
- Level 3 (blue): Consists of element A10.

This diagram (Fig.9) shows a relationship where Level 3 (A10) is at the top, followed by Level 2, and then Level 1 at the bottom. This structure is often used to describe the organization, classification, or dependency relationships between different elements.

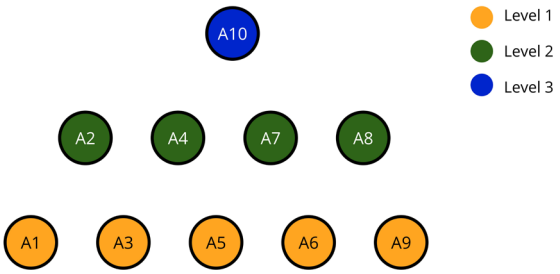


Fig. 9. Structuring food contamination prevention practices.

The level structure model is one of the IMS outputs that can be used as a reference material to determine the expected strategy in food contamination prevention efforts in hospitals. The results of this study show 4 expected strategies in food contamination prevention efforts where strategies at level 1 are key elements or can be said to be sub-elements of strategies with the highest driver power, while strategies at level 4 are sub-elements of strategies with the lowest driver power and have the highest dependence. The needs contained in level 1, washing hands before handling food, checking the expiration date of food products, cleaning kitchen surfaces before and after cooking, using gloves when handling food, and using clean water for cooking and washing food. These 5 things are key elements in fulfilling food contamination prevention strategies in hospitals. Meanwhile, level 3, namely ensuring food cooking temperatures reach safe standards, is a strategy that is at the base of the level structure.

Needs at Level 1 include washing hands before handling food, checking the expiry dates of food products, cleaning kitchen surfaces before and after cooking, using gloves when handling food, and utilizing clean water for cooking and washing food. These 5 practices are key elements in implementing strategies for preventing food contamination in hospitals. At Level 3, ensuring that food cooking temperatures meet established standards represents a foundational strategy within the hierarchical structure. Handwashing prior to food handling is a crucial step in preventing cross-contamination, particularly in kitchen environments. Research shows that reduced risk of effective handwashing, longer washing duration, education on proper handwashing techniques, and training to reduce the spread of pathogens.

V. Discussion

Escherichia coli is a common inhabitant of the gastrointestinal tracts of warm-blooded animals, including humans, where it plays a beneficial role by suppressing the growth of harmful bacterial species. However, some strains of *Escherichia coli* can cause disease in humans by producing enterotoxigenic toxins in the gastrointestinal tract [19–23].

Like other pathogenic bacteria, coliform bacteria undergo several stages in their pathogenic process. Pollutants can alter the gut microbiome and disrupt the gut barrier, leading to increased susceptibility to infection. These stages include cell division, the death of intestinal cells, colonization at specific sites on the intestinal surface (mucosal cells), bypassing intestinal cells to enter the circulation, attaching to target organs, and ultimately causing organ damage [24–26]. Although most *Escherichia coli* pathogens cause external damage to host cells, EIEC is an intracellular pathogen that can infect and multiply inside intestinal mucosal cells and macrophages [27, 28].

This section presents the average exposure values of *Escherichia coli* in different food types. The data reflect the number of bacterial colonies detected in each food sample, which serves as an indicator of contamination levels. Variations in colony counts across different foods indicate differing levels of contamination. These findings provide an important basis for assessing potential health risks to consumers [27].

The results of this study were subsequently analyzed using the QMRA method. QMRA is a process that enables quantitative assessment to estimate the risk of infection and disease from pathogenic microorganisms and has been widely applied in the evaluation of water and food [28]. The attachment of *Escherichia coli* to the intestinal mucosal surface is performed using a pilus (or P_{ill} if there are many of them). Each strain of *Escherichia coli* has a unique fimbriae structure that varies in size and function and is encoded by different virulence genes. The daily infection probability analysis shows the risk of consumers becoming infected with *Escherichia coli* after consuming contaminated food. All food types showed high probability values, indicating a significant risk of infection. The 'Gogos' food showed the highest probability of infection (2.52×10^{-1}, which means that consumers have about a 25% chance of being infected each time they consume the food. This leads to different mechanisms in each group of pathogenic *Escherichia coli* to cause damage to host cells. The pathogenic properties of *Escherichia coli* are categorized into several types based on the mechanism of pathogenicity, virulence, and clinical syndrome [29].

Kamala *et al.* [22] indicate the presence of food sanitation factors associated with *Escherichia coli* ($p = 0.03$). However, in this study, restaurant sanitation factors were not associated with *Escherichia coli* contamination, whereas the value of the sanitation factor was not associated with *Escherichia coli* contamination $p > 0.005$ [29]. *Escherichia coli* bacteria in food indicate fecal contamination, indicating that there is a risk of pathogenic bacteria. This contamination is a major source of foodborne illness, with significant implications for both public health and the economy, which impacts the economy and health [30].

Escherichia coli bacteria are rod-shaped, gram-negative, and fecal coliform bacteria found in the intestines of warm-blooded animals, including humans (as the primary habitat). After *Escherichia coli* is removed from its primary habitat (warm-blooded animals) through feces, most *Escherichia coli* will die due to low nutrients and other environmental factors [31]. However, *Escherichia coli* attached to soil, sediment, or algae surfaces can live longer and adapt to the environment. *Escherichia coli*, which adapts

and replicates in the environment, can re-enter its primary habitat through water and food [32].

Escherichia coli indicates potential contamination by other pathogens, which highlights the importance of monitoring its levels in food. For example, studies have shown that *Escherichia coli* is frequently detected in a variety of food matrices, including raw meat, dairy products, and fresh produce, which underlines the need for effective monitoring and control measures throughout the food supply chain. Identifying critical control points in food processing where contamination can occur is critical to implementing preventive measures [33].

The annual probability of infection was calculated based on the frequency of consumption of contaminated food throughout the year. The results of the analysis show that all foods fall into the high-risk category, meaning that consumers who regularly consume these foods have a high probability of experiencing an *Escherichia coli* infection in a year. These findings emphasize the need for more serious preventive measures to reduce health risks.

Based on the calculation results, the daily risk value of bacterial infection/daily infection probability ($P_{inf/day}$) of *Escherichia coli* is highest in the gogos food sample, which is 1×10^{1}. These results suggest that consumption of gogos may pose a daily risk of *Escherichia coli* bacterial infection. Exposure assessment is the next step in the QMRA. At this stage, the annual risk of infection from consuming contaminated food was calculated. The calculation results found that the annual risk probability $P_{inf/Yearly}$ due to *Escherichia coli* bacteria in food samples is >1, which means there is a risk of infection from *Escherichia coli* bacteria if Gogos is consumed for 1 year.

The main findings of this study confirm that regular consumption of foods contaminated with *Escherichia coli* O157:H7 carries a high risk of infection over a period of years. This result is consistent with previous studies and epidemiological studies that reported high cases of infection due to this food pathogen, especially from products such as ground beef and fresh vegetables [34]. Based on the annual infection probability analysis, all the food categories studied belong to the high-risk group, which confirms the importance of strictly implementing preventive measures, surveillance, and food quality control to reduce the public health impact of this bacterial contamination.

This exposure assessment involved measuring the levels of *Escherichia coli* present in food products and determining the frequency of consumption among different population groups. Studies have shown that consuming contaminated lettuce can lead to a significant risk of *Escherichia coli* infection, especially in vulnerable populations such as children and the elderly [22–26].

Risk characterization was the next step taken to characterize the risk of disease associated with the consumption of microbially contaminated food to gastrointestinal diseases, commonly referred to as disease probability (P_{ill}). Determination of risk characteristics is the final step in risk analysis, where information on toxicity and exposure is integrated into an 'upper bound estimate' of the health risk contained in a bacterium [27, 28].

Risk characterization integrates the findings from hazard identification, exposure assessment, and dose-response assessment to estimate the risk of *Escherichia coli* in food products. This step often involves the use of mathematical models to stimulate different scenarios and predict potential health impacts based on varying levels of exposure. The results of the *Escherichia coli* analysis on food samples yielded values ranging from 1.76×10 to 1×10, indicating that these food samples pose a high risk of causing health issues due to *Escherichia coli* contamination if consumed by humans. This finding aligns with research conducted on the microbial risk analysis of *Escherichia coli* in fresh lettuce, which reported a disease risk of 9.9×10^{8}, categorizing this risk as low [29].

Microbiological tests via Gram stain and biochemical tests confirmed the identification of the bacteria as *Escherichia coli*. The Gram stain results showed Gram-negative bacteria, which is the main characteristic of *E. coli*. Further biochemical tests revealed metabolic properties of the bacteria consistent with the characteristics of *E. coli*. These results are important for ensuring the accuracy of pathogen identification and determining appropriate treatment strategies.

Previous research confirms that Gram staining is an effective method to identify *E. coli* as a Gram-negative bacterium that has a thin cell wall and does not retain the crystal violet colour. Furthermore, biochemical tests such as the Methyl Red test, Indole test, Nitrate Reduction test, and Lactose fermentation gave positive metabolic reaction patterns typical of *E. coli*, distinguishing it from other bacteria. These results are consistent with the research conducted, where the combination of Gram stain and biochemical tests is essential for the accuracy of *E. coli* identification to support proper diagnosis and treatment strategies for infection [35, 36].

International research shows that the distribution of *E. coli* colonies in food varies widely and can occur at different stages of the food distribution chain, such as handling, storage, and transport. Most food samples were below the maximum safe limit, but higher contamination was found in certain types of food, posing a risk to consumer health. One study highlighted the need for close surveillance of contamination-prone foods during distribution, in line with the finding that Gogos-type foods had *E. coli* colony levels that exceeded safe limits, confirming the highest risk in these foods. Most samples were below the maximum allowable limit, except for Gogos food, which showed colony counts exceeding the safe limit. This finding reinforces the position of Gogos as the highest risk food and indicates the need for special attention to the processing and serving of this type of food. Another study points to the importance of good handling and storage practices to control *E. coli* contamination along the food supply chain.

Risk analysis uses a quantitative approach with formulas that consider factors such as the number of pathogens, the effectiveness of food processing, and the infectious dose. These formulae allow systematic calculation of exposure and potential infection, which can be used for a more objective evaluation of risk. This method also allows comparison of risk between different types of food [37–39].

Risk management that can be done to overcome the health risks experienced by consumers is to reduce the amount of bacterial contamination, especially *Escherichia coli*, in food,

and reduce the volume and duration of consumption [40]. The right strategy is needed to reduce the value of bacterial contamination in food, which can be in the form of improving restaurant sanitation and food handlers' education. In addition, implementing appropriate strategies and understanding and actions of food processors are also key factors in reducing bacterial contamination.

The Interpretative Structural Modelling (ISM) analysis of food contamination prevention strategies shows that 10 sub-elements play an important role in reducing the incidence of *Escherichia coli*-related illness in food. Handwashing prior to food handling is a fundamental step that must not be overlooked in any food safety management process [27]. These actions are not just routine but are the foundation of all food safety practices. Interpretative Structural Modelling (ISM) can be used to identify and map relationships between factors contributing to *Escherichia coli* risk in the context of food safety, as well as to identify and map relationships between health and environmental risks of exposure to chemicals such as heavy metals [32, 33], and to map relationships between different factors contributing to more effective pollution reduction strategies based on relationship analysis [34]. Analysis using Interpretative Structural Modelling (ISM) showed that of the 10 elements of strategies to address diarrhea, personal hygiene (washing hands before handling food) was the top priority. This strategy has a great influence in preventing food contamination and has low dependency on other strategies.

This study emphasizes that personal hygiene is a key element in food safety management in hospital settings. Regular hand washing is a very effective preventive measure in reducing the risk of *Escherichia coli* bacterial contamination, which can be transmitted through food that is not processed and served with poorly maintained sanitation procedures [41]. Within the Interpretative Structural Modeling (ISM) framework, personal hygiene occupies a strategic position as the main foundation of a holistic food safety management system.

The results of the Quantitative Microbial Risk Assessment (QMRA) showed a significant risk of infection from certain foods, such as gogos, consumed by patients and staff of RSUD Hajjah Andi Depu. This finding makes food safety policy in the hospital a top priority, even though the environment is generally kept clean. Therefore, it is very important to implement strict sanitation protocols starting from the selection of food ingredients, processing at high temperatures, storage at maintained temperatures, to safe serving.

Continuous training for food handlers should be prioritized to ensure they understand and implement optimal hygiene practices. Hospital management needs to establish regular monitoring systems at critical points in the food processing and serving chain to prevent potential contamination, including surveillance for flies and other environmental factors that can vector bacteria [42]. The consequences of food safety policies not being strictly implemented can be an increase in infection cases, increased healthcare costs, and damage to the hospital's reputation. Therefore, risk control measures should start at the processing stage by cooking at a sufficiently high temperature and maintaining proper storage temperatures before food is served to patients and staff.

We have also identified and discussed potential confounders and biases that may have affected the results of this study. Significant efforts were made to minimize such influences through a representative sampling design and standardized and rigorous analysis procedures [13]. In addition, confounding variables were statistically controlled during data analysis to ensure the validity and reliability of the study results. This approach is by the best practices recommended in the literature regarding the control of bias and confounders in epidemiological research and risk analysis, as reported by Luque *et al.* [43] and Quon *et al.* [44] which highlights the importance of thorough control over these variables to obtain accurate and reliable results in public health and pathogen risk studies.

We have also identified and discussed potential confounders and biases that may have affected the results of this study. Significant efforts have been made to minimize such influences through a representative sampling design and standardized and rigorous analysis procedures. In addition, confounding variables were statistically controlled during data analysis to ensure the validity and reliability of the study results. This approach is in accordance with best practices recommended in the literature related to controlling bias and confounders in epidemiological research and risk analysis.

Previous studies have shown that failure to control for confounders and bias can result in misguided risk estimates, leading to misleading interpretations of the data and potentially harming evidence-based decision-making [45]. Therefore, the measures we took not only strengthen the credibility of this study but also adhere to internationally recognized methodological standards in epidemiology and quantitative analysis of health risks.

In addition, considering the importance of data validity and reliability in this study, further research should be conducted to evaluate the effectiveness of various sanitation methods and behavioral interventions in hospital settings. A multidisciplinary approach and the utilization of innovative technologies are also highly recommended to develop food safety policies that are more adaptive and responsive to the dynamic conditions occurring in healthcare facilities.

VI. Conclusion

This study highlights the critical importance of understanding the risks posed by *Escherichia coli* contamination in food, particularly within hospital environments. By applying Quantitative Microbial Risk Assessment (QMRA) and Interpretative Structural Modeling (ISM) methodologies, this study successfully identified the key risk factors contributing to *Escherichia coli* contamination in food served to hospital staff. The analysis results showed that, among 5 food samples tested, 1 sample, Gogos, exceeded quality standard limits with a mean exposure value of 1200. Recommendations include implementing stricter hygiene practices, such as washing hands before food handling, separating raw and cooked foods, and ensuring safe cooking temperatures. Furthermore, this study suggests further research to explore new methods of controlling *Escherichia coli* contamination, including the development of more effective food processing technologies and educational strategies for food handlers on hygiene importance. Future studies should also experimentally

evaluate these control methods, conduct longitudinal monitoring of contamination trends, and investigate environmental factors influencing contamination risk. Thus, this study provides valuable insight into *Escherichia coli*-related health risks and paves the way for advancing food safety improvements in hospitals and other environments.

Conflict of Interest

The authors declare no conflicts of interest

Author Contributions

Patmawati: Conceptualization, Resources, writing original draft. Anwar Daud: Formal Analysis, Data curation. Anwar Mallongi: validation, investigation, Supervision. Agus Bintara Birawida: Methodology, Formal analysis, Project administration, writing-review & editing. Yuyun Yuniar: Formal analysis, Supervision. Muhammad Fahmi Aziz: Formal Analysis, Data curation. Saliza Mohd Elias: Conceptualization, Formal analysis, Supervision. All authors had approved the final version.

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