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FOOD AND WATER HYGIENE AS CRITICAL DETERMINANTS OF DIARRHEAL DISEASE: AN EPIDEMIOLOGICAL AND ENVIRONMENTAL HEALTH RISK ASSESSMENT IN PAYAKUMBUH CITY, INDONESIA

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ABSTRACT

Diarrheal disease persists as a significant public health challenge in Indonesian cities despite improvements in sanitation infrastructure. This study synthesizes epidemiological data, microbiological water quality assessments, and environmental health risk factors from Payakumbuh City, West Sumatra (2020–2024). Using Environmental Health Risk Assessment (EHRA) methodologies integrated with epidemiological surveillance, we conducted spatial risk mapping and household sanitation evaluation. Results showed a 24.3% reduction in diarrheal cases concurrent with modest water quality improvements. However, critical vulnerabilities remain: 10.8% of households rely on microbiologically contaminated wells (mean E. coli: 3,367 CFU/100mL), 65.2% of septic tanks lack professional emptying, and 85.1% of subdistricts face high-to-very-high wastewater management hazards despite 78.4% piped water coverage. The gap between aggregate infrastructure coverage and micro-level sanitation quality represents the principal challenge in tropical urban settings. Targeted interventions addressing septage management, household-level water treatment, and hygiene behavior transformation are essential to accelerate disease reduction and optimize resource allocation in resource-limited settings. The integration of EHRA with epidemiological surveillance provides an evidence-based framework for prioritizing public health investments.

Keywords: *Diarrheal disease epidemiology, Water quality and sanitation, Environmental health risk assessment, Urban tropical settings, Infrastructure-health gap*

INTRODUCTION

Diarrheal disease remains a leading cause of morbidity and mortality in early childhood in low- and middle-income countries, particularly in tropical regions where adequate water treatment and sanitation facilities are still limited. According to a World Health Organization report, more than 829,000 children die annually from diarrhea, and approximately 60% of these deaths could potentially be prevented through improved water services, sanitation, and hygiene practices [1] [2]. In Indonesia, diarrhea remains one of the ten most frequently reported infectious diseases in regional health surveillance systems.

The city of Payakumbuh illustrates a common public health paradox in urban areas of developing countries. This is evident in the relatively high aggregate coverage of sanitation infrastructure, yet certain population groups continue to bear the burden of disease due to unequal access to safe drinking water and functioning sanitation systems. Local health records show a decline in the number of diarrhea cases from 1,454 in 2020 to 1,139 in 2024, representing a cumulative decrease of approximately 21.7% over that period. While this trend is positive, the incidence rate, which remains far above that of developed countries, confirms that gaps in access to sanitation, water quality assurance, and daily hygiene practices continue to facilitate pathogen contamination in residential environments [3] [4].

1.1 RESEARCH GAP AND STUDY CONTRIBUTION

Although many previous studies have examined the correlation between water quality and diarrheal disease in rural and developing country contexts, studies that simultaneously integrate spatial mapping of Environmental Health Risk Assessments, microbiological analysis of water quality, and multi-year epidemiological surveillance are limited, particularly in tropical Southeast Asian urban settings. This study addresses these gaps through: (1) spatially explicit risk characterization that allows resource allocation to target affected subpopulations; (2) empirical identification of specific sanitation system failures relative to aggregate coverage metrics; and (3) integration of behavioral hygiene assessments with infrastructure analysis to develop more comprehensive intervention strategies.

1.2 RESEARCH OBJECTIVES AND QUESTIONS

This research aims to provide evidence-based guidance for health offices and related stakeholders in setting investment priorities for sanitation and designing water and sanitation systems that are resilient to climate change. This research focuses on three key interrelated questions regarding water and sanitation management in Payakumbuh City:

1) What is the current status of water quality and sanitation infrastructure in Payakumbuh City, and where are critical vulnerabilities concentrated geographically?
2) What quantitative associations exist between water quality improvements and reductions in diarrheal disease incidence?
3) Which targeted interventions—addressing infrastructure gaps, household-level water treatment, and behavioral practices—are most likely to achieve sustainable disease reduction in resource-limited tropical urban settings?

METHODOLOGY

2.1 Study Design and Type of Research

This study employed a mixed-methods design combining a systematic literature review with case study analysis. The literature review section summarizes published epidemiological data, microbiological water quality measurement results, and environmental health risk factors that explain the link between water safety, sanitation practices, and diarrheal disease transmission. The case study section examines city surveillance data, Environmental Health Risk Assessment results, and water quality laboratory analysis in Payakumbuh City, West Sumatra, from 2020 to 2024. This integrated approach allows for a simultaneous review of global epidemiological evidence with contextualized disease conditions and trends at the local level.

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2.2 Payakumbuh City Case Study: Data Collection

2.2.1 Study Setting

Payakumbuh City, located in West Sumatra Province, Indonesia, has a population of approximately 180,000 people spread across four districts and 47 villages. It is a medium-sized city with a mixed pattern of formal and informal settlements, limited industrial activity, and a heavy reliance on public health infrastructure operated by city and provincial government agencies.

2.2.2 Water Quality Laboratory Analysis

Laboratory microbiological analysis of 11 representative well water samples collected from locations distributed across Payakumbuh City's municipal territory revealed universal contamination with E. coli, with contamination levels substantially exceeding both Indonesian national standards and WHO guidelines. Specific findings included:

Table 1. Microbiological Standards for Drinking Water

Standard	E.coli (CFU/100mL)	Total coliform (CFU/100mL)	pH	TDS (mg/L)	Iron (mg/L)	Manganese (mg/L)
The Indonesia Minister of Health Regulation	0	0	6.5-8.5	< 500	< 0.3	< 0.4
WHO guidlines	0	0	6.5-8.5	≤ 1,000	≤0.3	≤ 0.10

Note: should be placed under the table leaving no space in-between; 12-pt font; and left- and right-justified.

2.2.3 Environmental Health Risk Assessment Survey

The Environmental Health Risk Assessment (EHRA) survey was conducted in 2022 by the Payakumbuh City Health Office, covering 1,880 households systematically spread across 47 sub-districts. Data collection used the Community-Based Total Sanitation (STBM) assessment framework, which evaluates five important environmental health domains: (1) access to and quality of water sources; (2) domestic wastewater disposal; (3) solid waste management systems; (4) presence of stagnant water; and (5) participation in the Clean and Healthy Living Behavior (PHBS) program. EHRA data surveillance involved observations and interviews with households to characterize sanitation conditions. The results of the sub-district-level survey produced a Sanitation Risk Index score categorized as low risk, moderate risk, or high/very high risk.

2.2.4 Epidemiological Surveillance Data

Data on diarrheal disease cases were obtained from the Payakumbuh City in Figures book published annually by the Central Statistics Agency, covering a five-year period from 2020 to 2024. This data comes from reports of confirmed diarrhea cases by the Payakumbuh City Health Office at each health facility in the city. Meanwhile, the Water Quality Index (WQI) value is calculated annually based on physical and chemical parameters of surface water quality monitored by the Environmental Laboratory Technical Implementation Unit (UPTD) at the Payakumbuh City Environmental Office.

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2.2.5 Data Analysis

Quantitative analysis calculated trends in Water Quality Index values and verified incidence of diarrheal disease cases during the 2020–2024 observation period using descriptive statistics (mean, range, percentage change calculation). Correlation analysis used Pearson correlation coefficient to assess the relationship between annual WQI values and the number of diarrheal cases. Spatial analysis of Sanitation Risk Index scores characterized the geographic distribution of sanitation vulnerability across villages through village-level risk categorization. Cross-tabular analysis examined the relationship between specific sanitation infrastructure failures (septic tank maintenance status, well proximity to human waste sources, piped water coverage) and documented levels of microbiological contamination.

REVIEW CONCEPTS AND THEORIES

3.1 Pathophysiological Mechanisms Linking Water Contamination to Diarrheal Disease

The transmission of diarrheal pathogens through contaminated water sources involves multiple biological and environmental mechanisms. Escherichia coli and related enteric bacteria, along with viral agents including rotavirus and parasitic organisms such as Giardia, establish infection through fecal-oral transmission pathways—predominantly water-mediated when sanitation infrastructure fails to contain human sewage [5]. Microbiological indicators, particularly the presence of thermotolerant (fecal) coliform bacteria and E. coli, serve as sentinel markers for fecal contamination and associated health risks. Epidemiological evidence indicates that water sources exceeding E. coli concentrations of 1,000 CFU/100mL substantially elevate the odds of diarrheal disease—with meta-analytic syntheses documenting increased disease risk between 2.5-fold and 3.8-fold across exposed populations [6] [7].

3.2 Pathogenic Agents and Transmission Mechanisms

3.2.1 Bacterial Pathogens and Fecal-Oral Transmission

Bacterial diarrheal disease results from fecal-oral transmission of enteric pathogens through contaminated water and food. Pathogenic *Escherichia coli* strains represent one of the most prevalent bacterial causes of diarrhea globally, with multiple pathogenic phenotypes including enteropathogenic *E. coli* (EPEC), enteroinvasive *E. coli* (EIEC), and particularly enterohaemorrhagic *E. coli* (EHEC) variants capable of producing Shiga toxins and inducing hemorrhagic colitis with potential systemic complications [13]. Transmission occurs predominantly through fecal-oral routes, facilitated by consumption of contaminated water sources, undercooked or inadequately processed foods, or direct contact between individuals with compromised hygiene practices. The 1980 Walkerton outbreak in Ontario, Canada—resulting in approximately 2,300 confirmed cases and seven fatalities—exemplified the epidemic potential of *E. coli* O157:H7 following municipal water system contamination, underscoring the critical importance of water treatment integrity and distribution system maintenance [14].

Salmonella represents the principal bacterial cause of foodborne illnesses globally, with salmonellosis characterized by acute gastroenteritis typically presenting 8–72 hours following ingestion of contaminated foodstuffs. Symptomatically, affected individuals experience acute-onset diarrhea, abdominal cramping, systemic fever, plus constitutional manifestations including myalgia and headache. Epidemiological evidence identifies vulnerable subpopulations—including infants, elderly persons, and immunocompromised individuals—

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as bearing substantially elevated risks for invasive infection and fatal outcomes [15]. *Salmonella* contamination occurs throughout the complete food supply chain from primary agricultural production through retail distribution networks. Poultry and poultry-derived products represent major reservoirs, with epidemiological studies documenting that 20–50% of raw poultry samples in developed countries contain *Salmonella* species—with higher prevalence anticipated in low-income settings constrained by limited cold-chain infrastructure [16]. Cross-contamination during food preparation—when raw and ready-to-eat items contact shared surfaces, or when food handlers practice inadequate hand hygiene—constitutes a critical intervention control point for preventing foodborne salmonellosis outbreaks [17].

Shigella species cause bacillary dysentery characterized by mucoid diarrhea and, in severe presentations, visible blood in stool. The organism demonstrates remarkable epidemiological significance in regions with inadequate sanitation infrastructure, with research from South and Southeast Asia attributing 5–15% of acute diarrheal episodes in children under five to *Shigella* infection [18]. Unlike Salmonella and pathogenic *E. coli*, which frequently originate from animal reservoirs, *Shigella* exists primarily as a human-restricted pathogen, suggesting predominantly person-to-person transmission through fecal contamination of food and water supplies [19]. The organism's epidemiological patterns exhibit tight linkage to environmental sanitation conditions; indeed, geographic distribution and incidence of shigellosis serve as sensitive indicators of sanitation system failure and inadequate sewage treatment. In settings where human fecal matter contaminates water supplies—through direct discharge or through agricultural irrigation using untreated sewage—the transmission risk for *Shigella* increases substantially. Institutional outbreaks within childcare facilities have been extensively documented, demonstrating the organism's capacity for rapid transmission when hygienic practices are compromised [20].

3.2.2 Viral Pathogens: Gastroenteritis and Fecal-Oral Transmission

Rotavirus constitutes the most prevalent viral cause of acute gastroenteritis among children globally, with an estimated 200,000 deaths annually attributable to *Rotavirus* infection in children under five years of age. The virus manifests characteristic epidemiological patterns, with peak incidence occurring during winter months in temperate climatic regions and throughout the calendar year in tropical zones demonstrating year-round transmission [21] [22]. *Rotavirus* infection predominantly affects children between 3–35 months of age, with peak incidence clustering approximately 24 months, though infection can occur across broader age ranges in settings with elevated pathogen circulation intensity [23].

Rotavirus transmission occurs predominantly via the fecal-oral route through four primary transmission pathways: consumption of contaminated food, ingestion of microbiologically unsafe water, contact with unsanitary fomites, and direct hand-to-mouth contact following contamination with infectious fecal matter [24]. Viral particles demonstrate remarkable environmental persistence, remaining viable and infectious for extended periods—characteristically several days to weeks—within environmental matrices, thus facilitating indirect transmission through contaminated surfaces and objects. In institutional settings including childcare facilities and hospitals where multiple young children congregate in close proximity, rotavirus demonstrates explosive epidemic transmission patterns with secondary attack rates frequently exceeding 50–70% [25].

Clinically, *rotavirus* infection produces distinctive clinical features including acute-onset watery diarrhea, prominent vomiting (occurring in approximately 85% of rotavirus cases compared to 68% of non-rotavirus gastroenteritis episodes), and systemic fever. The pronounced vomiting accompanying rotavirus infection distinguishes it from bacterial diarrheal agents and substantially elevates dehydration risk through combined fluid losses

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from both diarrhea and emesis [23]. The characteristic incubation period is brief, typically 24–48 hours, after which symptomatic disease manifestation occurs.

Rotavirus pathophysiology involves dual complementary mechanisms: osmotic diarrhea resulting from malabsorption secondary to viral-mediated destruction of intestinal enterocytes, and secretory diarrhea mediated by non-structural protein 4 (NSP4), functioning as a secretory enterotoxin [26]. Viral infection compromises the absorptive capacity of the small intestinal epithelium, reducing the intestinal capacity to absorb essential sodium, glucose, and water—elements normally retained through normal intestinal physiological processes. This combined malabsorption-secretion mechanism explains the characteristic severe, profuse watery diarrhea associated with *Rotavirus* and the pronounced dehydration risk, particularly acute in young children with limited physiological capacity to compensate for substantial fluid losses [27].

3.2.3 Parasitic Pathogens: Waterborne Transmission

Giardia lamblia (also designated Giardia intestinalis or Giardia duodenalis) represents one of the most common parasitic causes of diarrhea globally, with particularly elevated prevalence in resource-limited settings characterized by inadequate water treatment infrastructure and deficient sanitation systems [28]. The parasitic protozoan colonizes the small intestinal epithelium, producing a spectrum of clinical manifestations ranging from asymptomatic infection to severe malabsorptive diarrhea accompanied by weight loss and nutritional deficiency states [29].

Transmission of *Giardia* occurs exclusively through ingestion of cysts excreted in feces, with cysts maintaining viability and infectivity for durations up to three months in cold water environments. Primary transmission routes include person-to-person contact (particularly within childcare settings and among family members sharing domestic spaces), consumption of contaminated water supplies, and ingestion of foods prepared using microbiologically unsafe water [28] [29]. The role of contaminated water as a transmission vehicle carries particular significance; waterborne outbreaks have been extensively documented in both developed countries (associated with inadequate water treatment of surface water sources) and developing countries (characterized by absence of water treatment infrastructure) [30].

The disease spectrum of giardiasis ranges from asymptomatic infection (occurring in approximately 10–20% of infected individuals) to acute watery diarrhea persisting 1–2 weeks, extending to chronic giardiasis characterized by intermittent loose stools and malabsorptive symptoms persisting for months or years. Epidemiologically significant, both symptomatic and asymptomatic infected individuals excrete infectious cysts, thereby facilitating ongoing transmission within community networks. Children in childcare facility settings represent high-risk acquisition groups, with prevalence studies documenting infection rates of 10–30% among children in such settings in developing countries [28].

3.3 Food Safety Management Systems and Preventive Frameworks

3.3.1 Hazard Analysis and Critical Control Point (HACCP) Methodology

Food safety management systems represent structured, systematic approaches to identifying and controlling hazards throughout food supply chains, from primary agricultural production through consumer consumption endpoints. The Hazard Analysis and Critical Control Point (HACCP) methodology provides the foundational framework adopted internationally, involving systematic identification of potential biological, chemical, or physical hazards at specific production steps designated as critical control points, coupled with establishment of monitoring procedures and corrective action protocols to ensure hazard

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control [43].

HACCP implementation requires formal documentation of hazard analysis, specification of critical limits at each control point, establishment of monitoring procedures with defined measurement frequencies, and delineation of corrective actions deployed when critical limits are exceeded [44].The methodology has demonstrated effectiveness in reducing foodborne illness outbreaks when rigorously implemented and monitored, with studies documenting substantial reductions in pathogenic contamination rates in food service establishments and manufacturing facilities employing HACCP systems [45].

3.3.2 ISO 22000 and FSSC 22000 Certification Standards

ISO 22000 provides an internationally recognized systematic framework integrating HACCP principles with prerequisite program components and overarching management system requirements, establishing hierarchical control structures for food safety [29]. The Food Safety System Certification 22000 (FSSC 22000) expands upon ISO 22000 by incorporating sector-specific prerequisite programs and additional requirements established by the Global Food Safety Initiative (GFSI) [46]. FSSC 22000 certification, recognized by major international retailers and multinational food manufacturers, requires organizations to demonstrate compliance with ISO 22000 requirements, sector-specific technical specifications for hygienic production environments, and scheme-specific requirements [47]. Certification audit procedures and ongoing compliance monitoring ensure sustained adherence to food safety standards [48].

3.3.3 British Retail Consortium (BRC) and International Featured Standards (IFS)

The British Retail Consortium (BRC) and International Featured Standards (IFS) represent additional GFSI-recognized certification schemes designed to ensure food safety and quality across global supply chains [29]. The BRC scheme encompasses nine essential operational sections: senior management commitment, HACCP-based food safety planning, integrated food safety and quality management systems, facility standards, product control measures, process control procedures, personnel competency and hygiene protocols, high-risk/high-care production environment management, and traded product requirements [48]. The comprehensive checklist approach—encompassing more than 300 specific control points—ensures systematic evaluation of facility conditions, equipment maintenance status, staff hygiene compliance, and product safety measures.

3.4 Sanitation, Hygiene Practices, and Behavioral Interventions

3.4.1 Hand Hygiene and Food Preparation Safety

Effective hand washing represents one of the most cost-effective interventions for preventing diarrheal disease transmission, with particular importance within food preparation contexts where contaminated hands directly contact food destined for consumption. Proper hand hygiene technique—involving washing with soap and warm water for minimum 20-second duration, with particular attention to fingertips, interdigital spaces, and thumb surfaces—removes vegetative bacteria and enveloped viral particles from skin surfaces [49]. Critical hand washing moments include: before food preparation, after handling raw animal products, after toilet use, after diaper handling, and after other personal hygiene activities. Food handlers experiencing diarrhea or confirmed foodborne pathogen infection present particularly elevated transmission risks, necessitating exclusion from food preparation duties until clinical recovery and microbiological clearance (typically 48 hours post-symptom resolution) [50]. In childcare settings—where rotavirus and Giardia transmission commonly occurs through contaminated diaper contact—systematic implementation of hand hygiene protocols has demonstrated effectiveness in reducing disease incidence by 30–50% [51].

3.4.2 Environmental Sanitation and Fecal Containment

Environmental sanitation, particularly effective fecal disposal through functioning latrine systems or sewage infrastructure, constitutes a foundational requirement for diarrheal disease prevention. Studies consistently demonstrate that households lacking access to improved sanitation facilities—defined as latrines preventing direct contact between human feces and food/water environments—experience substantially elevated diarrheal disease risk [52]. Latrine cleanliness maintenance through regular cleaning and prevention of fly breeding habitat within fecal material reduces both direct water contamination pathways and vector-mediated transmission of pathogens [53].

RESULT

4.1. Environmental and Climatic Determinants of Disease Transmission

4.1.1. Temperature Effects on Pathogen Proliferation and Disease Incidence

Epidemiological evidence demonstrates a robust quantitative association between ambient temperature anomalies and increased incidence of infectious diarrhea, particularly among children under five years of age. Temperature influences diarrheal disease incidence through multiple biological pathways: warmer ambient temperatures accelerate bacterial reproduction rates within contaminated food and water matrices, extend the survival duration of pathogenic organisms, and facilitate arthropod vector proliferation within appropriate ecological niches [31]. A population-based investigation examining relationships between climatic variables and diarrheal disease incidence in Taiwan identified statistically significant associations between monthly average temperature anomalies and all-cause infectious diarrhea in children under five years, with statistical significance demonstrated for specific temperature threshold ranges [32]. Similarly, research conducted in Nepal documented that monthly diarrheal case numbers increased by 8.1% per 1°C increase in maximum ambient temperature [32]. Conversely, extremely low temperature conditions demonstrate a protective epidemiological effect on viral diarrhea transmission, possibly through mechanisms involving reduced fecal-oral contact frequency and decreased environmental survival duration of specific viral pathogens [33].

4.1.2. Precipitation Patterns, Hydrological Conditions, and Waterborne Disease

The epidemiological relationship between precipitation patterns and diarrheal disease incidence demonstrates complex, context-dependent associations requiring nuanced interpretation. High- intensity precipitation events can facilitate waterborne disease transmission through multiple interconnected mechanisms: overland runoff from contaminated agricultural land carries bacterial and parasitic pathogens into surface water sources; sewage system overflows during heavy rainfall events directly contaminate urban water supplies; and increased surface water turbidity may overwhelm treatment plant capacity to achieve adequate pathogenic particle removal [34].

However, the temporal pattern of precipitation relative to baseline hydrological conditions substantially influences both the direction and magnitude of disease transmission risk. When heavy precipitation follows extended dry periods, accumulated pathogenic organisms in terrestrial environments are flushed rapidly into water sources, producing acute increases in waterborne disease transmission. Conversely, precipitation falling during or immediately following wet seasons may dilute pathogen concentrations within surface water matrices, reducing transmission risk. These context-dependent associations highlight the necessity of

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weather-based early warning systems that account for baseline hydrological conditions and characteristic seasonal patterns rather than responding mechanistically to precipitation thresholds alone [35].

4.1.3. Climate Change and Emerging Disease Risks in Tropical Regionsrecipitation Patterns, Hydrological Conditions, and Waterborne Disease

Climate change manifests through alterations in mean temperature regimes, increased precipitation variability, and elevated frequency of extreme weather events—all carrying substantial implications for diarrheal disease epidemiology in vulnerable regions. Projections suggest that a global temperature increase of 4°C would substantially elevate diarrheal disease incidence, with particular impacts anticipated in tropical and subtropical regions already burdened by elevated baseline disease levels [36]. The combined effects of temperature increase, precipitation variability, and potential geographic expansion of areas suitable for pathogenic transmission suggest that climate change will increase absolute disease burden in low-income regions unless substantial adaptation investments in water, sanitation, and hygiene infrastructure are implemented concurrently [37].

4.2. Water Quality Assessment and Microbiological Contamination Patterns

4.2.1. WHO Guidelines and Drinking Water Quality Parameters

The World Health Organization establishes internationally recognized guidelines for drinking water quality, specifying maximum allowable concentrations for microbiological, physical, chemical, and radiological parameters. Microbiological parameters establish the requirement for complete absence of fecal indicator bacteria (including E. coli and Enterococcus species), with zero tolerance mandated for fecal contamination in treated drinking water supplies. Physical parameters include turbidity (typically limited to 0.5–1.0 Nephelometric Turbidity Units), color, taste, and odor—characteristics influencing consumer acceptability and water treatment process effectiveness. Chemical parameters specify maximum permissible concentrations for inorganic contaminants (including arsenic, fluoride, lead, nitrate) and organic contaminants (including pesticide residues, disinfection byproducts) [2].

Regulatory compliance requires that municipal water supplies consistently achieve specified standards at consumer-accessible taps, necessitating treatment of raw water through sequential processes including coagulation, flocculation, sedimentation, and filtration, with subsequent disinfection employing chemical or physical methods to eliminate microbial pathogens. The maintenance of residual disinfectant concentration throughout distribution systems—typically 0.2–0.5 mg/L free chlorine—prevents microbial regrowth and provides protection against post-treatment contamination occurring through pipe leakage or system pressurization loss [38].

4.2.2. Microbiological Contamination in Payakumbuh City: Findings from Laboratory Analysis

Laboratory microbiological analysis of 11 representative well water samples collected from locations distributed across Payakumbuh City's municipal territory revealed universal contamination with E. coli, with contamination levels substantially exceeding both Indonesian national standards and WHO guidelines. Specific findings included:

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Table 2. Laboratory Analysis of Well Water Samples

Location	E.coli (CFU/100mL)	pH	TDS (mg/L)	Iron (mg/L)	Manganese (mg/L)
Labuah Basilang	13,400	6.10	210	0.45	2.10
Tanjung Pauh	12,100	5.90	225	0.60	3.20
SMP 2 Payakumbuh	5,400	6.20	170	0.12	1.70
Ibuh	1,200	5.80	180	0.25	5.82
Koto Panjang	900	6.00	160	1.16	0.45
Bulakan Balai Kandi	100	5.90	150	0.03	2.10
Kubu Gadang	500	7.00	688	0.38	0.98
Sicincin	2,100	6.90	120	0.08	0.13
Padang Tiakar	3,367	6.83	152	1.00	2.20
Ampangan	1,400	5.58	55	0.40	0.85
Tigo Koto Dibalai	1,800	7.27	130	0.60	0.27
The Indonesia Minister of Health Regulation Standard	0	6.5-8.5	< 500	< 0.3	< 0.4
WHO Standard	0	6.5-8.5	≤ 1,000	≤0.3	≤ 0.10

Source: Environmental Laboratory Unit, 2022.

4.2.3. Mechanisms of Well Water Contamination

The predominance of elevated *E. coli* concentrations in well samples likely stems from three interconnected factors [39] [40]:

1) Inadequate spatial separation: Proximity of wells to septic tanks insufficient (<10 meters in 73% of EHRA-documented cases) permits microbial penetration into groundwater aquifers;
2) Deficient septage management: 65.2% of septic tank systems documented by EHRA survey have never received professional emptying, allowing pathogen accumulation and infiltration;
3) Hydrogeological vulnerability: Porous soil characteristics facilitate lateral groundwater contamination through preferential flow pathways.

4.3. Environmental Health Risk Assessment and Spatial Risk Mapping

4.3.1. EHRA Survey Methodology and Sanitation Risk Index

The Environmental Health Risk Assessment survey conducted in 2022 encompassed 1,880 households distributed across 47 municipal subdistricts, employing the Community-Based Total Sanitation (STBM) assessment framework. The Sanitation Risk Index (SRI) integration evaluated five critical environmental health components:

1) Water source access and quality;
2) Domestic wastewater management;
3) Solid waste disposal systems;
4) Stagnant water presence;
5) Clean and Healthy Living Behavior (PHBS) program participation.

4.3.2. Spatial Distribution of Sanitation Risks

Spatial analysis of SRI scores across municipal subdistricts revealed heterogeneous risk distributions:

1) Water Sources (57% low risk, 43% high/very high risk): The majority of subdistricts demonstrate low-to-moderate risk for water source access. This pattern indicates

reliable access to clean water supplies in most areas, likely reflecting PDAM (Regional Water Company) infrastructure coverage of 78.4% of households.

2) Wastewater Management (85.1% high/very high risk): The highest risk concentration occurs in the wastewater component, reflecting ongoing challenges in domestic wastewater management infrastructure. This finding directly correlates with EHRA documentation that 65.2% of septic tanks have never undergone professional emptying, with presence of seepage and overflows, and substandard construction standards [8].
3) Solid Waste Management (44.7% low risk, 23.4% moderate risk, 31.9% high/very high risk): Solid waste management demonstrates relatively even distribution across risk categories, indicating that waste management infrastructure requires targeted improvements in approximately 55% of subdistricts.
4) Stagnant Water (55.3% low risk, 10.7% high risk): Stagnant water conditions demonstrate relatively favorable status, with drainage systems functioning adequately in most subdistricts, though certain peripheral areas remain vulnerable to water accumulation.
5) PHBS (Clean and Healthy Living Behavior) (17% low risk, 53.2% moderate risk, 29.8% high/very high risk): PHBS assessment reveals persistent gaps in community hygiene practices, with approximately 53% of subdistricts categorized at moderate risk and 30% at high-to-very-high risk. This distribution reflects inadequate handwashing practices, deficient household sanitation practices, and insufficient waste separation behavior [8]. Despite relatively high compliance rates for Handwashing with Soap (CTPS) at 92.1%, only 17% of subdistricts achieve low-risk classification based on comprehensive PHBS-SRI scoring. More than 30% of subdistricts face high-to-very-high risk, primarily driven by poor waste sorting practices (only 13% of households separate waste), inconsistent food hygiene practices, inadequate child hygiene, and suboptimal public facility sanitation [8]. The SRI Risk Distribution in Payakumbuh City can be seen in the image below.

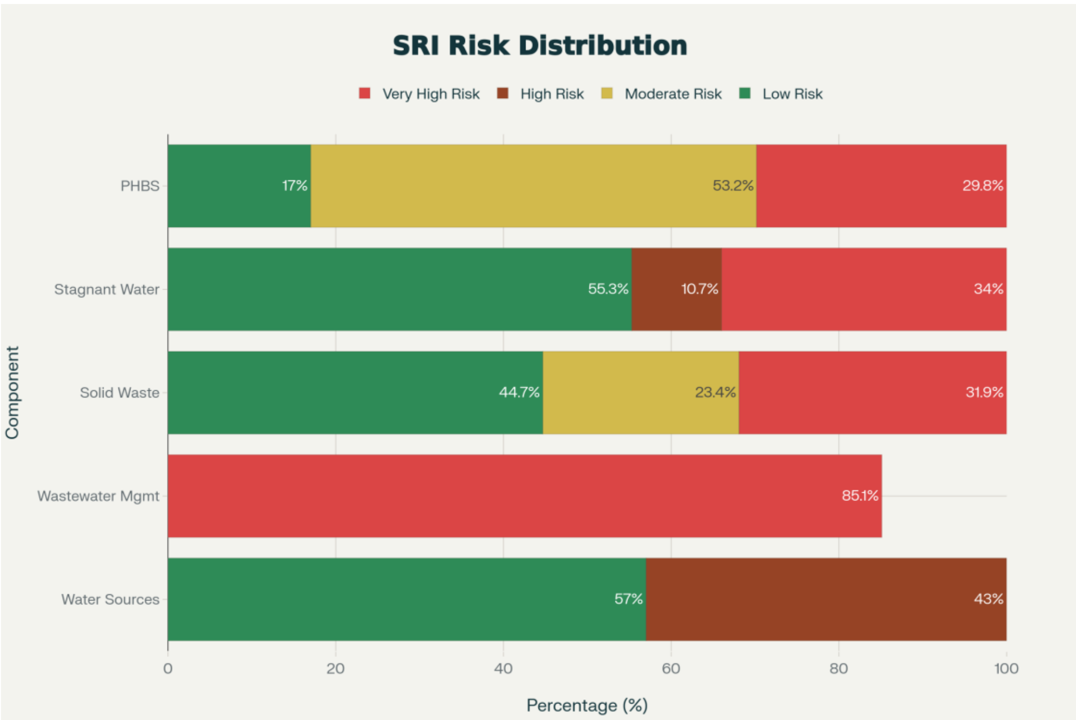

Fig.1 SRI Risk Distribution in Payakumbuh City

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4.4. Epidemiological Trends: Water Quality Index and Diarrheal Disease Incidence

4.4.1. Temporal Trends (2020–2024)

Five-year analysis of Water Quality Index (WQI) trends and diarrheal disease case reports revealed parallel patterns:

Table 3. Trends of Water Quality Index (WQI) and Diarrhea Cases in Payakumbuh City, 2020–2024

Year	Water Quality Index (WQI)	Diarrhea Cases	Diarhea Cases Change (%)
2020	41.00	1,454	-
2021	55.14	1,291	-11.2
2022	44.21	1,260	-2.4
2023	45.26	1,139	-9.6
2024	46.80	1,101	-3.3

Source: BPS-Statistics Payakumbuh Municipality. (2025).

4.4.2. Correlation Analysis Between Water Quality and Disease Incidence

Quantitative correlation analysis revealed a weak negative association between Water Quality Index values and reported diarrheal case numbers (Pearson's $r = -0.27$). While this correlation coefficient suggests modest statistical association, the consistent inverse pattern across the five-year observation period indicates that improved water quality demonstrates protective epidemiological association with reduced diarrheal disease occurrence [41].

The most pronounced epidemiological response to water quality improvement occurred during the 2020–2021 transition period, when the WQI experienced its highest single-year increment (14.14 points), coinciding with the most substantial diarrheal case reduction (163 cases; 11.2% decrease). This temporal coincidence provides suggestive evidence that focused water quality improvement interventions produce measurable positive public health impacts.

4.4.3. Disease Burden and Economic Impact

The estimated annual economic burden of diarrheal disease in Payakumbuh City approximates 1.9 billion Indonesian Rupiah, calculated from estimated 38,000 cases and mean treatment cost of 50,000 rupiahs per patient. This figure represents only direct medical expenditures and excludes substantial indirect costs including lost workdays, reduced productivity, and family-level economic burden— elements that epidemiologists estimate are 2–3 times greater than direct treatment costs [42]. This economic burden falls disproportionately on lower- income families, exacerbating cycles of poverty, malnutrition, and susceptibility to infectious disease.

4.5. Integration of Climate Adaptation and Food Safety Systems: Operationalization in Payakumbuh City

4.5.1. Weather-Based Early Warning Systems

Integration of meteorological monitoring with disease surveillance systems enables identification of high-risk periods for diarrheal disease outbreaks, facilitating timely deployment of preventive interventions. In tropical regions characterized by distinct wet and dry seasonal cycles, diarrheal disease incidence typically peaks during or immediately following monsoon seasons, corresponding temporally with heavy precipitation events and elevated water contamination risk [54]. Early warning systems combining weather forecasts,

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epidemiological baselines, and real-time water quality monitoring can alert public health authorities to anticipate increased disease burdens, mobilize supplementary treatment resources, and intensify community-level hygiene promotion efforts [55].

4.5.2. Climate-Resilient WASH Infrastructure Development

Climate change adaptation requires that water supply infrastructure be engineered to maintain treatment and distribution system integrity despite projected precipitation variability and increased frequency of extreme weather events. This necessitates investment in multiple water source diversification (including groundwater reserves and surface water facilities), treatment system redundancy, backup power generation for water treatment facilities, and distribution system infrastructure repairs addressing pipe leakage and pressure loss phenomena during high-demand periods [56]. Simultaneously, sanitation system upgrades must accommodate increased stormwater flows during extreme precipitation events, preventing sewage overflow and wastewater system failures that generate acute waterborne disease transmission risks [57].

4.6. Evidence-Based Intervention Recommendation

4.6.1. Short-Term Interventions (0–12 months)

1) Mass septic tank evacuation: Priority implementation in high-risk subdistricts identified through spatial SRI mapping, with special attention to Kubu Gadang, Sicincin, and Padang Tiakar subdistricts.
2) Well disinfection programs: Immediate implementation of chlorination protocols or provision of household point-of-use water treatment solutions (ceramic filtration or chlorine-based disinfection) for all wells remaining in active use.
3) Vulnerable population support: Emergency assistance programs targeting economically disadvantaged communities heavily dependent on contaminated well supplies.

4.6.2. Medium-Term Interventions (1–3 years)

1) PDAM network expansion: Scaling piped water coverage to >95% of municipal households, with prioritization of peripheral subdistricts currently dependent on well systems.
2) Wastewater treatment infrastructure: Rehabilitation or construction of cluster-based or communal sanitation and wastewater treatment facilities, particularly in high-risk subdistricts.
3) Laboratory capacity strengthening: Implementation of integrated real-time monitoring systems for Sanitation Risk Index tracking and epidemiological surveillance, utilizing data dashboards for epidemic response coordination.
4) PHBS promotion intensification: Enhanced Clean and Healthy Living Behavior education targeting schools, workplaces, and community organizations, with emphasis on waste sorting practices and food hygiene protocols.

4.6.3. Long-Term Interventions (3+ years)

1) Sustainable septage management policies: Development and promotion of risk-based labeling systems and financial incentive mechanisms for regular professional septic tank maintenance.
2) Multi-sector collaboration frameworks: Formalization of partnerships engaging municipal government, private sector entities, community-based organizations, and

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international development agencies in adaptive, climate-resilient water and sanitation management.

3) Technical innovation advancement: Integration of molecular microbiological monitoring techniques and spatial risk mapping approaches to promote evidence-based decision-making and sustained risk reduction.

4.7. Study Limitations and Future Research Directions

4.7.1. Methodological Constraints

This research incorporates data from multiple sources with inherent limitations that warrant acknowledgment:

1) Observational design limitation: The correlational research design restricts ability to establish definitive causal associations between water quality parameters and diarrheal disease occurrence
2) Temporal and spatial constraints: Data collection encompasses specific timeframes and selected well locations, potentially omitting seasonal variations or micro-spatial risk heterogeneity
3) Sample representativeness: The 11 well water samples may not fully capture contamination variability across the entire municipal territory
4) Surveillance data quality: Passive disease surveillance systems may underestimate true diarrheal disease incidence by 40–60% due to unreported mild cases and undertreatment episodes [58].
5) Confounding factor control: Insufficient systematic control or stratification for confounding variables including hygiene behavior, nutritional status, healthcare accessibility, and socioeconomic factors that independently influence disease risk.
6) Limited parameter assessment: Water quality analysis encompassed only selected microbiological and chemical parameters, excluding assessment of emerging contaminants or specific pathogenic agents.
7) Intervention effectiveness: The study did not evaluate effectiveness of concurrently implemented interventions, limiting ability to attribute disease reduction to specific programmatic components.

4.7.2. Future Research Priorities

Future investigations should address identified limitations through:

1) Longitudinal molecular epidemiology: Implementation of nested case-control designs with molecular source tracking to identify specific contamination pathways and validate intervention targets.
2) Expanded water quality assessment: Integration of molecular microbial community analysis and pathogenic organism-specific detection alongside conventional indicators.
3) Multi-level confounding analysis: Systematic collection and analysis of household-level behavioral, nutritional, and socioeconomic data to enable stratification and effect modification assessment.
4) Intervention effectiveness evaluation: Implementation of rigorous quasi-experimental or experimental designs to quantify the independent contribution of specific water quality, sanitation, and hygiene interventions to disease reduction.
5) Climate resilience integration: Development of climate adaptation strategies specifically tailored to tropical urban settings, incorporating sea level rise, precipitation variability, and temperature anomaly projections.

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CONCLUSION

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Food and water hygiene, operationalized through comprehensive sanitation system development and supported by standardized food safety management frameworks, represent primary mechanisms for reducing diarrheal disease burden in Indonesian municipalities and comparable tropical urban settings. The empirical evidence synthesized in this investigation demonstrates that pathogenic contamination of food and water supplies—mediated through bacterial, viral, and parasitic agents— occurs predictably within contexts characterized by poor sanitation infrastructure and inadequate hygienic practices. Conversely, systematic implementation of hazard control measures—from water treatment and distribution system integrity through food handler training and latrine maintenance— produces substantial documented reductions in disease occurrence.

The Payakumbuh City case exemplifies a common paradox: achievement of substantial aggregate coverage for basic sanitation infrastructure concurrent with persistence of critical gaps affecting vulnerable subpopulations. The 10.8% of households maintaining reliance on microbiologically contaminated wells, despite 78.4% aggregate PDAM coverage, represents a concentrated disease risk burden. Similarly, the universal microbiological contamination of tested wells and widespread failure of septic tank maintenance (65.2% never emptied) indicate that infrastructure gaps persist despite aggregate coverage statistics.

The weak but consistent negative correlation between Water Quality Index improvements and reduced diarrheal disease incidence ($r = -0.27$), coupled with spatial documentation of sanitation vulnerability through EHRA methodology, provides evidence-based guidance for targeted intervention prioritization. Future progress in diarrheal disease control requires:

1) Sustained investment in WASH infrastructure expansion in developing regions, prioritizing systems reaching economically disadvantaged populations bearing highest disease burden.
2) Localized food safety systems implementation appropriate to local economic and institutional contexts, with particular emphasis on informal food enterprises operating within urban poor communities.
3) Climate adaptation strategies ensuring water supply and sanitation system resilience in face of projected climate-driven precipitation variability and temperature anomalies.
4) Behavioral health communication addressing hygiene practices, particularly hand washing and fecal-oral transmission prevention through community-engaged approaches.

These investments constitute not only public health imperatives but also fundamental development requirements, with diarrheal disease control enabling improved childhood nutrition, enhanced educational attainment, and increased productive economic capacity across affected populations— ultimately contributing to accomplishment of Sustainable Development Goal 6 (Clean Water and Adequate Sanitation) and related health equity objectives across Indonesian municipalities.

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