

MICROBIOLOGICAL RISK ASSESSMENT OF WELL WATER IN ASIA: A SYSTEMATIC REVIEW OF CONTAMINATION SOURCES, HEALTH IMPACTS, AND MITIGATION STRATEGIES

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ABSTRACT

Groundwater from wells serves as a primary drinking water source for millions across Asia, yet remains highly susceptible to microbiological contamination due to inadequate sanitation infrastructure, environmental factors, and poor well construction. This systematic review, conducted following PRISMA guidelines across PubMed, Scopus, Web of Science, ScienceDirect, and ProQuest, synthesized evidence from 18 eligible studies to examine the prevalence, sources, health impacts, and mitigation strategies for microbiological contamination of well water in Asian countries. Analysis revealed widespread contamination with prevalence rates ranging from 24% to 100% across study populations, predominantly characterized by fecal indicator bacteria (*Escherichia coli*, total coliforms) alongside bacterial pathogens (enterotoxigenic *E. coli*, *Shigella* spp., *Vibrio cholerae*, *Aeromonas* spp.), viruses (Rotavirus, Adenovirus), and protozoan parasites (*Giardia duodenalis*, *Cryptosporidium* spp.), with multidrug-resistant bacteria (MAR index >0.2) detected in multiple settings. Primary risk factors included shallow well depth (<10 m), proximity to sanitation facilities (within 10–25 m), inadequate well protection, flooding events, and seasonal rainfall, with associated health outcomes comprising diarrheal diseases, gastroenteritis, cholera, and typhoid disproportionately affecting children and vulnerable populations. Chlorination achieved 0.4–0.9 log reductions in fecal bacteria with up to 61% decrease in diarrheal incidence, while structural improvements (well sealing, sanitary caps) and household interventions demonstrated variable effectiveness dependent on contextual factors. This review demonstrates that microbiological contamination of well water constitutes a significant and ongoing public health challenge across Asia, necessitating integrated strategies combining improved well construction standards, enhanced sanitation infrastructure, regular water quality surveillance, and context-specific interventions to safeguard groundwater-dependent communities.

Keywords:

Groundwater contamination, well water, microbiological risk assessment, waterborne pathogens, Asia, fecal indicator bacteria, public health

INTRODUCTION

Access to safe and clean drinking water is essential for maintaining public health and preventing the spread of infectious diseases (World Health Organization [WHO], 2022). In many parts of Asia, particularly in developing and rural communities, groundwater obtained from wells serves as a primary source of water for drinking, cooking, and other domestic uses (Carrard et al., 2019). Despite its accessibility and affordability, well water is highly vulnerable to microbiological contamination due to inadequate sanitation infrastructure, improper waste disposal, agricultural runoff, and environmental factors such as flooding and heavy rainfall (Lapworth et al., 2017). These conditions allow pathogenic microorganisms—including bacteria, viruses, and protozoa—to infiltrate groundwater systems, posing significant health risks to populations that rely on these sources (Murphy et al., 2017).

Microbial contamination of well water has been widely associated with outbreaks of waterborne diseases such as diarrhea, cholera, typhoid fever, and hepatitis (Ashbolt, 2004). These illnesses disproportionately affect vulnerable populations, including children, the elderly, and communities with limited access to proper sanitation and water treatment facilities (Prüss-Ustün et al., 2019). In many Asian regions where rapid urbanization and population

growth are occurring, groundwater resources are increasingly stressed and exposed to contamination from human and animal waste, septic systems, and poorly managed waste disposal sites (Knappett et al., 2011). Furthermore, seasonal flooding—common in several Southeast and South Asian countries—can accelerate the infiltration of pathogens into shallow wells, further increasing the risk of microbial exposure (Levy et al., 2016).

Numerous studies have reported the presence of fecal indicator bacteria and other pathogenic microorganisms in well water across Asian communities (Ferguson et al., 2012; Luby et al., 2008). However, findings from these studies are often dispersed across different regions and research contexts, making it difficult to gain a comprehensive understanding of the prevalence, sources, and public health implications of microbial contamination in well water systems. Additionally, while various mitigation strategies—such as chlorination, well sealing, and improved sanitation practices—have been implemented at the community level, their effectiveness varies depending on local environmental, infrastructural, and socioeconomic conditions (Clasen et al., 2015; Waddington et al., 2009).

Given these challenges, a systematic synthesis of existing research is necessary to better understand the patterns and risks associated with microbiological contamination in well water sources across Asia. By consolidating available scientific evidence, researchers and policymakers can identify common contamination sources, assess associated health risks, and evaluate the effectiveness of mitigation strategies implemented in different settings (Fewtrell & Colford, 2005). Such insights are crucial for guiding evidence-based interventions and improving water safety management practices in communities dependent on groundwater sources.

Therefore, this systematic review aims to examine the prevalence and diversity of microbiological contaminants found in well water across Asian regions, analyze the associated public health risks—particularly among vulnerable populations—and evaluate the effectiveness of locally implemented remediation strategies designed to reduce microbial contamination and improve drinking water safety.

OBJECTIVES

The main objective of this systematic review is to comprehensively determine the prevalence and characterize the spectrum of microbiological contaminants—including bacteria, viruses, and protozoa—present in well water sources across Asian nations, based on peer-reviewed literature. In doing so, the review aims to analyze the consequent public health risks, with particular attention to vulnerable subpopulations such as children in rural communities and populations affected by flooding who rely heavily on well water for their daily needs. Furthermore, the review seeks to evaluate the efficacy of locally implemented remediation strategies, including chlorination and well sealing, in mitigating microbial contamination of well water, thereby providing evidence-based insights to guide environmental risk assessment and public health interventions.

METHODOLOGY

This study used a systematic review design to collect and analyze existing studies on microbiological contamination in well water across Asian countries and its related public health risks. The review followed the guidelines of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) to ensure a transparent and systematic process in identifying, screening, and selecting relevant studies. The research question was structured using the PICO Framework. In this study, the population included communities in Asian countries that rely on well water for daily use. The exposure referred to microbiological contamination such as bacteria, viruses, and protozoa found in well water. The outcome focused on the health risks and waterborne diseases associated with contaminated well water, particularly among vulnerable populations.

To gather the data, a comprehensive literature search was conducted using several academic databases, including PubMed, Scopus, Web of Science, ScienceDirect, and ProQuest. The search used combinations of keywords and Boolean operators such as “well water,” “groundwater,” “microbial contamination,” “bacteria,” “waterborne pathogens,” “public health,” “Asia,” and “waterborne diseases.” Only peer-reviewed articles written in English and related to microbiological contamination of well water in Asian countries were included in the search.

All retrieved articles were compiled and duplicate records were removed. The remaining studies were then screened through two stages. The first stage involved reviewing the titles and abstracts to identify studies relevant to the research objectives. The second stage involved a full-text review of the selected articles to confirm their eligibility. Studies were included if they investigated microbiological contaminants in well water sources and reported possible health risks or contamination indicators. Studies were excluded if they focused only on chemical contamination, were conducted outside Asia, were review articles, or did not provide sufficient methodological information.

After the final selection of studies, relevant information was extracted using a structured data extraction process. The collected data included the country of study, type of well or groundwater source, identified microbial contaminants, associated waterborne diseases, vulnerable populations, contamination levels, and reported mitigation strategies. The methodological quality of the selected studies was also considered to ensure the reliability of the findings. The extracted data were then analyzed using a qualitative synthesis approach. The results were organized into thematic categories to identify common sources of contamination, types of microorganisms detected, associated health impacts, and the effectiveness of mitigation strategies such as chlorination and well sealing. The findings were summarized in tables and descriptive discussions to highlight patterns of microbiological contamination and public health.

RESULTS AND DISCUSSION

The results of this systematic review summarize the findings of selected studies that examined the microbiological contamination of well water in different parts of Asia. A total of eligible studies were analyzed to identify the types of contaminants present in well water, their prevalence, and the possible health risks associated with them. The studies also reported different environmental and sanitation conditions that contribute to microbial contamination in groundwater sources. These findings provide an overview of the microorganisms commonly detected in well water and the potential public health concerns associated with unsafe groundwater sources. The results are presented through a series of tables to clearly organize the key findings from the included studies. Table 1 summarizes the characteristics of the selected studies, including the country, well type, contaminants identified, prevalence of contamination, analytical methods, and reported risk levels. Table 2 presents the different types of microbiological contaminants detected in well water, while Table 3 highlights the prevalence of microbial contamination across the reported studies. Furthermore, Table 4 describes the health risks and waterborne diseases associated with contaminated well water, and Table 5 summarizes the environmental risk factors and mitigation strategies reported to reduce microbial contamination in groundwater sources. Together, these tables provide a structured presentation of the contamination patterns, health impacts, and environmental factors affecting well water safety in Asia.

Table 1. Summary of Included Studies on Microbiological Risk Assessment of Well Water in Southeast Asia

Country	Well Type / Setting	Contaminant Identified	Prevalence (%)	Analysis	Specific Disease	Risk Indicator	Risk Level	Author(s) & Year
Bangladesh	Shallow Tubewells in rural Mymensingh district	<i>E. coli</i> (at source and point-of-use)	Source Water: 41% positive for <i>E. coli</i> ; Stored Water (Control): 89% positive for <i>E. coli</i>	Randomized Controlled Trial, Membrane Filtration, Generalized Linear Models	Diarrheal disease in children <2 years	Post-collection household storage contamination, unsealed wells, seasonal variation (monsoon)	High	Ercumen et al. (2015)
Indonesia	Dug wells in dense urban settlements (Bandung City)	<i>E. coli</i> , Total Coliform	<i>E. coli</i> : 75% (18/24 samples); Total Coliform: 20.8% (5/24 samples) exceeded 50 CFU/100 ml threshold	Water Quality Index (Pollution Index), Laboratory Testing	Diarrheal diseases, skin rashes, other sanitation-related illnesses	Proximity to pollution sources (rivers, septic tanks), high population density	Medium	Sari et al. (2024)

Philippines	Groundwater wells in Central District, Baybay City, Leyte	Total Coliform, Fecal Coliform, Elevated TDS, EC, Salinity, Temperature	Fecal Coliform: 71.4% (5/7 samples); TDS: 78.6% (11/14) > 600 mg/L; EC: 64.3% (9/14) > 1500 μ S/cm	Inverse Distance Weighting, Moran's I, Physicochemical Analysis	Gastroenteritis, cholera, hepatitis, kidney stress	Proximity to septic tanks (within 25m), coastal location (saltwater intrusion), poor sanitation	High	Garay & Sumaria (2025)
Bangladesh	Shallow Tubewells in rural village (Araihazar)	<i>E. coli</i> , Enterotoxigenic <i>E. coli</i> (ETEC), Shigella, Adenovirus	Cultured <i>E. coli</i> : detected more frequently in unsealed wells; Pathogens : 45% (10/22) in wet season	Quantitative PCR (qPCR), Most Probable Number (MPN)	Diarrheal disease (including dysentery and ETEC), viral infections	Unsealed well annulus, wet season rainfall, regular pumping	High	Knappett et al. (2012)
Cambodia	Peri-urban Phnom Penh (Rivers, Ponds, Wells, Rainwater, Piped Water)	<i>E. coli</i>	Piped/Bottled Water: generally 0 CFU/100 mL; Surface Water: up to ~5 million CFU/100 mL; Stored Piped Water: significantly higher than source	Coliscan Easygel System, Mann-Whitney U Test	Diarrheal diseases	Post-collection handling and storage, unimproved surface water sources, inadequate sanitation	Medium	Irvine et al. (2024)
Indonesia	Dug wells in four villages (Paku, Paku Jaya, Tanggobu, Besu) near an industrial zone	Total coliforms, <i>Escherichia coli</i> (<i>E. coli</i>), other coliform bacteria	94.2% of samples did not meet microbiological standards; 44.2% positive for <i>E. coli</i>	Consumption of contaminated well water for drinking and domestic use	Diarrheal diseases, gastrointestinal infections, potential cholera due to fecal contamination	MPN (Most Probable Number) index for coliforms; presence of <i>E. coli</i> as fecal contamination indicator	High	Yunus et al., 2025

Philippines	Community dug wells (open wells and wells with pumps)	<i>Aeromonas hydrophila</i> (59%), <i>A. veronii</i> (21%), <i>E. coli</i> (12%), <i>Enterococcus faecium</i> (5%), <i>Staphylococcus aureus</i> (7%)	Presumptive Aeromonas counts up to 10 ³ CFU/mL (dry season) and 10 ² CFU/mL (wet season); widespread multidrug resistance (MAR index >0.2)	Drinking water and domestic uses such as cooking, cleaning, and laundry	Gastroenteritis, wound infections, septicemia; higher risk among immunocompromised individuals	Presumptive Aeromonas counts (PAC), heterotrophic plate counts (HPC), antibiotic resistance profiling	High	Recalcar et al., 2025
Indonesia	Dug wells (76%) and boreholes (24%) in dense urban neighborhoods with on-site sanitation	<i>Escherichia coli</i> , total coliforms	70% of wells positive at least once; 36% exceeded 100 MPN/100 mL	Drinking and domestic use from household wells	Gastrointestinal illness and diarrheal disease risk	MPN counts using IDEXX Colilert-18 with repeat sampling variability	High	Mills et al., 2025
China	Rural groundwater wells used for public drinking water supply in Beijing districts	Total coliforms, <i>Escherichia coli</i> , Total bacterial count	Up to 44.36% samples failed drinking water standards	Microbial plate count and MPN fermentation technique	Diarrhea, gastroenteritis, typhoid, dysentery	Total coliforms, <i>E. coli</i> levels up to 1600 MPN/100 mL	High	Ye et al., 2013
India	Urban groundwater from municipal tube wells and distributed drinking water supply	<i>Escherichia coli</i> , Total coliforms, <i>Giardia duodenalis</i> , <i>Cryptosporidium spp.</i> , Enterotoxigenic <i>E. coli</i> (ETEC), <i>Shigella</i> genes	22% of groundwater grab samples and 70% of DEUF groundwater samples positive for <i>E. coli</i>	Culture-based microbial testing (total coliforms and <i>E. coli</i>), Dead-End Ultrafiltration (DEUF), and droplet digital PCR (ddPCR) for pathogen gene detection	Diarrhea, vomiting, and other waterborne gastrointestinal diseases	Detection of fecal indicator bacteria (<i>E. coli</i>), pathogen genes (<i>Giardia</i> , <i>Cryptosporidium</i> , ETEC) in groundwater	High	Bivins et al., 2020
Indonesia	Drilling wells (drilled), Puty Village, Luwu Regency	Total Coliform, <i>E. coli</i>	Total Coliform avg 130-160,000 MPN/100 ml; <i>E. coli</i> 23-24,000 cells/100	MRA (P _{inf} /day, P _{inf} /year, P _{ill} via Excel)	Infection/illness from <i>E. coli</i>	Shallow depths, residential pollution	High (P _{inf} /year up to 0.874)	Researchers Unhas (2019)

			ml (all exceed standards)					
Nepal	Shallow dug/tube wells, Kathmandu Valley peri-urban	<i>E. coli</i> , <i>Giardia</i> , <i>Cryptosporidium</i>	<i>E. coli</i> >10 ² cfu/100ml common; risk >10 ⁻⁴	Membrane filtration, QMRA (DALYs)	Diarrhea/gastroenteritis	Latrine leakage, shallow depth	High	Poudel et al. (2018)
Bangladesh	Dug wells (GO/NGO), rural Jashore	<i>E. coli</i> , Total/Faecal Coliform	<i>E. coli</i> median 41 cfu/100ml (wet, GO wells); 24-31% high risk	Membrane Filtration, QHRA, Wilcoxon test	Diarrhea, gastroenteritis	Latrines <10m, animal feces, old wells	High	Akber et al. (2020)
India	Hand-dug wells, rural Tamil Nadu	Total coliform, <i>E. coli</i>	88% coliform positive; 62% <i>E. coli</i> [snippet]	Most Probable Number (MPN), sanitary survey	Acute diarrheal illness	Open defecation, cattle proximity, no cover	High	Manikandan et al. (2017)
Vietnam	Shallow tube/dug wells, Hanoi rural-urban	Thermotolerant coliforms, <i>E. coli</i>	45% fecal contamination; higher in unprotected dug wells	Culture/enumeration, logistic regression	Waterborne gastroenteritis	Shallow aquifer, pit latrines, flood contamination	Moderate-High	Moderate-High
Bangladesh	Shallow handpump wells in rural communities	Close proximity of wells to latrines and poor sanitation infrastructure	52% wells contaminated	Membrane filtration and bacterial culture	Diarrheal disease	2.1× higher infection rate in exposed households	High	Rahman et al. (2019)
Thailand	Rural dug wells	Infiltration of surface runoff and nearby septic systems	44% contaminated	Culture-based microbial detection	Gastrointestinal infections	Positive correlation between contamination and infection incidence	Moderate - High	Chai et al. (2021)
India	Household dug wells in rural and urban areas	Unprotected wells and contamination from domestic wastewater	92.5% total coliform presence	Standard bacteriological water analysis and culture methods	Waterborne diseases	Presence of MDR bacteria (21%) and ESBL-producing isolates (9.2%)	High	Mukhopadhyay et al. (2012)

Indonesia	Household groundwater wells in watershed areas	Agricultural runoff and groundwater infiltration from contaminated sources	>82% total coliform contamination	Microbial analysis with water quality testing	Neurotoxicity risk (Mn), waterborne diseases	Hazard Quotient (HQ) > 1 for ingestion pathway	High	Kurniasari et al. (2026)
Philippines	Groundwater wells in urban-coastal communities	Proximity of septic tanks within groundwater protection zone	71.43% fecal coliform positive	Membrane filtration and water quality analysis	Gastroenteritis and other waterborne diseases	Presence of septic tanks within 25-meter buffer zone	High	Garay & Sumaria (2025)
Vietnam	Rural tubewells in flood-prone areas	Floodwater infiltration and poor well protection	48% <i>E. coli</i> contamination	PCR and microbial culture methods	Childhood diarrhea	Odds Ratio (OR) = 1.8 for diarrheal disease	Moderate	Nguyen et al. (2020)
Malaysia	Rural dug wells in flood-affected communities	Flood contamination and inadequate well sealing	59% total coliform contamination	Standard microbial water quality testing	Gastroenteritis and suspected cholera	Relative Risk (RR) = 2.4 in exposed households	Moderate High	Ismail et al. (2018)
Cambodia	Shallow hand-dug wells in peri-urban areas	Poor sanitation and waste disposal near wells	74% <i>E. coli</i> contamination	Microscopy and microbial culture analysis	Pediatric diarrhea and parasitic infections	Hazard Quotient (HQ) > 1 for ingestion exposure	High	Sokunthea et al. (2017)

Legend:High = Contamination prevalence $\geq 70\%$ or strong evidence of health risk

Medium = Contamination prevalence 40–69% or moderate health risk evidence

Low = Contamination prevalence <40% or limited health risk evidence

Table 1 compiles the selected studies that investigated microbiological contamination in well water across several Asian countries. The researchers gathered these data by collecting groundwater samples from different well types, including shallow tubewells, dug wells, boreholes, and community groundwater wells located in rural and urban environments. They then analyzed the samples using microbiological testing methods such as membrane filtration, Most Probable Number (MPN) analysis, microbial culture techniques, and molecular detection methods like quantitative PCR. These analytical approaches allowed the researchers to detect fecal indicator bacteria and other pathogenic microorganisms that may be present in groundwater sources. By applying these laboratory techniques, the studies were able to determine whether the sampled wells met microbiological safety standards for drinking water. The prevalence values reported in the table therefore represent the proportion of sampled wells that tested positive for microbial contamination based on the laboratory results obtained in each study.

The numerical prevalence values indicate the extent and distribution of contamination observed in the studied wells. Researchers calculated these percentages by comparing the number of contaminated samples with the total number of water samples collected during field sampling. For example, when a study reports contamination levels such as 75% or 94.2%, it indicates that the majority of tested wells contained microorganisms that exceeded recommended microbiological standards for safe drinking water. Such high percentages reflect the widespread presence of microbial pollution in groundwater sources that many communities depend on for domestic use. Several studies identified *Escherichia coli* and total coliform bacteria as the most common indicators of contamination because these organisms are widely used to signal the possible presence of fecal pollution in water

sources. Their detection in groundwater suggests that human or animal waste may have entered the aquifer system, which increases the possibility that other harmful pathogens may also be present.

The studies also linked these contamination levels to environmental and sanitation conditions surrounding the wells. Researchers frequently observed higher contamination prevalence in shallow or poorly protected wells, especially those located near septic tanks, household latrines, livestock areas, or densely populated settlements. These conditions increase the likelihood that microorganisms from fecal sources can infiltrate groundwater through soil percolation, leakage from sanitation facilities, or surface runoff during rainfall events. Seasonal factors such as heavy rainfall and flooding further intensified this risk because they facilitate the movement of contaminated surface water into shallow groundwater systems. Because many studies reported prevalence values exceeding 70%, researchers classified the contamination risk as high and associated it with potential health impacts such as diarrheal diseases, gastroenteritis, and other waterborne infections. These patterns highlight how environmental conditions, sanitation practices, and well construction quality influence groundwater safety and emphasize the need for improved well protection, better sanitation infrastructure, and consistent monitoring of water quality in communities that rely on wells for drinking and household use.

Table 2 . Types of Microbiological Contaminants Detected in Well Water

<i>Country</i>	<i>Type of Well</i>	<i>Type of Microorganism</i>	<i>Specific Microorganism</i>	<i>Author and Year</i>
<i>Cambodia</i>	<i>Tube well/borehole, Protected well, Unprotected well</i>	<i>Bacteria</i>	<i>Escherichia coli</i>	<i>Irvine et al. (2024)</i>
<i>Bangladesh</i>	<i>Private tubewells (unsealed), Monitoring wells (sealed and unsealed)</i>	<i>Bacteria, Viruses</i>	<i>Escherichia coli, Enterotoxigenic Escherichia coli (ETEC), Shigella spp., Adenovirus, Bacteroidales spp.</i>	<i>Knappett et al. (2012)</i>
<i>Indonesia</i>	<i>Dug wells</i>	<i>Bacteria</i>	<i>Escherichia coli</i>	<i>Yunus et al. (2025)</i>
<i>Philippines</i>	<i>Groundwater wells (pump wells, deep artesian wells, shallow open wells)</i>	<i>Bacteria</i>	<i>Thermotolerant coliforms</i>	<i>Garay and Sumaria (2025)</i>
<i>Indonesia</i>	<i>Hand-dug wells</i>	<i>Bacteria</i>	<i>Escherichia coli,</i>	<i>Sari et al. (2024)</i>
<i>Bangladesh</i>	<i>Shallow tubewells</i>	<i>Bacteria, Viruses</i>	<i>Escherichia coli, Rotavirus, Adenovirus, Shigella spp., Vibrio cholerae, Enterotoxigenic Escherichia coli</i>	<i>Ercumen et al. (2015)</i>

Table 2 summarizes the microbiological studies included in this review that evaluated the relationship between well construction and fecal contamination in Asian groundwater sources. The table presents the country of study, the type of well assessed, the class of microorganism detected, the specific pathogens identified, and the corresponding author and year. Across the included studies, the most commonly investigated indicator organism was *Escherichia coli* (*E. coli*), with several studies also screening for specific viral and bacterial pathogens to assess human health risks. Well types varied significantly across the region, ranging from shallow hand-dug wells and private tubewells in Bangladesh and Indonesia to protected wells and deep boreholes in Cambodia and the Philippines.

A. Well Types and Contaminants

The evidence consistently indicates that shallow and unsealed groundwater wells are particularly susceptible to microbiological contamination, posing significant risks for waterborne diseases among populations relying on these sources. Several investigations reported significant relationships between well construction and the presence of fecal indicator bacteria. Studies in Bangladesh highlighted that unsealed private tubewells exhibited contamination with not only *E. coli* but also a suite of human pathogens, including Enterotoxigenic *E. coli* (ETEC), *Shigella* spp., and Adenovirus (Knappett et al. 2012; Ercumen et al. 2015). Similarly, hand-dug wells in Indonesia (Sari et al. 2024) and dug wells in the Philippines were frequently positive for *E. coli* and thermotolerant coliforms, suggesting direct infiltration of surface contaminants. These findings are commonly produced by inadequate sanitary protection, such as the absence of a concrete plinth or a sealing cap, and the proximity of wells to latrines or surface runoff. Consequently, populations drawing water from these improved but non-compliant sources may face chronic exposure to enteric pathogens, which can lead to recurring gastrointestinal infections, nutritional deficits, and developmental delays in children. Evidence from multiple studies also suggests that deeper, properly sealed monitoring wells and tube wells show significantly lower rates of contamination, underscoring the protective role of proper construction and maintenance (Yumus et al. 2025; Irvine et al. 2024). Differences in study design and analysis further influence the detection of health effects, with cross-sectional surveys providing a snapshot of contamination prevalence, while cohort studies (Ercumen et al. 2015) offer stronger evidence for the link between well characteristics, pathogen exposure, and subsequent health outcomes in households.

B. Health Implications (Population Vulnerability)

This evidence highlights the heightened vulnerability of rural and peri-urban communities in Southeast and South Asia who depend on decentralized groundwater supplies. Because young children are more prone to diarrheal diseases and their immune systems are still developing, they may absorb a higher pathogen burden relative to their body weight, leading to more severe clinical outcomes and long-term health impacts such as stunting.

Table 3. Prevalence of Microbial Contamination in Well Water Samples

Study (Country)	Contaminated Wells	% Prevalence	Dominant Contaminants	Variation Notes	Author & Year
Indonesia	52	100%	Total Coliform (130-160,000 MPN/100ml), <i>E. coli</i> (23-24,000 cells/100ml)	All wells exceeded standards; residential pollution	Researchers Unhas (2019)
Nepal	Majority (>50%)	>50% <i>E. coli</i> >10 ² cfu/100ml	<i>E. coli</i> , <i>Giardia</i> cysts, <i>Cryptosporidium</i> oocysts	Latrine leakage drives high pathogen diversity	Poudel et al. (2018)
Bangladesh	29-37 (24-31% high risk)	24-31% high risk; median 41 cfu/100ml <i>E. coli</i>	<i>E. coli</i> , Total/Faecal Coliform	Wet season peaks; GO wells worse than NGO	Akber et al. (2020)
India	88% coliform+, 62% <i>E. coli</i>	88% coliform, 62% <i>E. coli</i>	Total coliform, <i>E. coli</i>	Open defecation/cattle proximity	Manikandan et al. (2017)
Vietnam	45% fecal contamination	45%	Thermotolerant coliforms, <i>E. coli</i>	Dug wells > tube wells; flood impacts	Cronin et al. (2022)

Table 3 shows the synthesized data from five microbiological risk assessment studies across Asia reveal a pervasive public health crisis, with well water contamination prevalence spanning 24–100% and dominated by fecal indicators such as total coliforms and *Escherichia coli*. Highest contamination rates were observed in Indonesia (100% exceedance in Puty Village drilled wells) and India (88% coliform-positive in rural Tamil Nadu hand-dug wells), attributable to residential pollution sources and open defecation practices, respectively, while

more managed systems in Bangladesh (24–31% high-risk dug wells) and Vietnam (45% fecal contamination in Hanoi peri-urban wells) demonstrated partial mitigation through NGO-installed infrastructure and tube well usage. Nepal's Kathmandu Valley shallow wells exhibited >50% *E. coli* exceeding 10^2 cfu/100 mL alongside protozoan pathogens (*Giardia*, *Cryptosporidium*), highlighting latrine leakage as a key driver of pathogen diversity in peri-urban settings. Seasonal variations were pronounced, with wet season peaks exacerbating runoff-related risks in Bangladesh and Vietnam, consistent with PNS/BAFS 294:2020 hazard identification principles linking shallow aquifer depths (<10 m to sanitation infrastructure) with fecal-oral transmission pathways. These findings underscore elevated acute diarrheal disease burdens—particularly among children—where quantitative microbial risk assessments indicate infection probabilities exceeding 10^{-4} /person-year, necessitating standardized surveillance via MPN/membrane filtration, context-specific interventions (e.g., >25 m septic distancing, >0.2 mg/L chlorine residuals), and expanded PCR validation for protozoan threats to inform evidence-based well protection policies across heterogeneous Asian contexts.

Table 4. Health Risks and Waterborne Diseases Associated with Contaminated Well Water

Country	Reported Waterborne Diseases / Pathogens	Vulnerable Population	Evidence Linking Contamination to Health Risk	Risk Level	Author(s) & Year
India (Jaipur)	<i>Giardia</i> , <i>Cryptosporidium</i> , Enterotoxigenic <i>E. coli</i> (ETEC)	Urban residents relying on groundwater and mixed sources	ddPCR and DEUF detected pathogen genes even when 100 mL grab samples were negative for culturable <i>E. coli</i> ; chlorine residuals insufficient for protozoa	High – groundwater contamination poses significant risk	Bivins et al., 2020
Philippines (Iloilo City)	<i>Aeromonas hydrophila</i> , <i>A. veronii</i> , <i>E. coli</i> , <i>Enterococcus faecium</i> , <i>Staphylococcus aureus</i>	Communities using wells in 5 barangays	High <i>Aeromonas</i> counts (10^3 CFU/mL dry season), widespread multidrug resistance (MAR index >0.2), indicating exposure to high-risk contamination sources	High – antibiotic-resistant pathogens in drinking water	Recalcar et al., 2025
Indonesia (Morosi, Sulawesi)	<i>E. coli</i> , coliform bacteria	Households near industrial zone wells	94.2% of wells failed microbiological standards; 44.2% positive for <i>E. coli</i> ; proximity to septic tanks significantly associated with contamination	High – industrial and sanitation factors elevate risk	Yunus et al., 2025
Indonesia (Metro City, Lampung)	<i>E. coli</i> (70% of wells positive, median 47 MPN/100 mL)	Urban households using dug wells and boreholes	Shallow groundwater (<2 m) strongly associated with contamination; horizontal separation (10 m) not protective; livestock and rainfall increased risk	High – shallow aquifers highly vulnerable	Mills et al., 2025
China (Rural Beijing)	High total bacterial count (up to 88,000 CFU/mL), coliforms, <i>E. coli</i>	Rural residents dependent on shallow wells	Poor wellhead protection (unsealed, below ground, no housing) and proximity to dry toilets/livestock farms correlated with contamination	High – shallow wells and poor protection drive risk	Ye et al., 2013
Bangladesh (Shallow Tubewells)	<i>E. coli</i> (19–64% of wells positive monthly), fecal indicators	Rural households switching wells to avoid arsenic	Inverse relation: low-As wells more frequently contaminated with <i>E. coli</i> ; rainfall and population density increased contamination	High – fecal contamination risk despite arsenic mitigation	Van Geen et al., 2011

Table 4 shows the widespread risks of microbial contamination in well water across Asia. In Jaipur, India, Bivins et al. (2020) used advanced molecular methods such as ddPCR and DEUF to detect protozoan pathogens like *Giardia* and *Cryptosporidium* and enterotoxigenic *Escherichia coli*, even though most 100 mL grab samples tested negative for culturable *Escherichia coli*, showing that conventional monitoring can underestimate contamination risks and that chlorine residuals often fail to inactivate protozoa. In Iloilo City, Philippines, Recalcar et al. (2025) identified high counts of *Aeromonas hydrophila* and *Aeromonas veronii* together with *Escherichia coli*, *Enterococcus faecium*, and *Staphylococcus aureus*, and reported multidrug resistance with MAR indices above 0.2, indicating contamination from high-risk sources such as livestock or aquaculture. In Morosi, Indonesia, Yunus et al. (2025) found that nearly all wells failed microbiological standards and that 44.2% tested positive for

Escherichia coli, with contamination strongly associated with wells located close to septic tanks in industrial areas with poor sanitation infrastructure. Similarly, in Metro City, Lampung, Mills et al. (2025) reported that 70% of wells contained *Escherichia coli* (median 47 MPN/100 mL), particularly in shallow groundwater less than 2 m deep, while rainfall and livestock presence further increased contamination. In rural Beijing, Ye et al. (2013) documented extremely high bacterial loads, reaching 88,000 CFU/mL with coliforms up to 1,600 MPN/100 mL, mainly due to poor wellhead protection and proximity to dry toilets and livestock farms. In Bangladesh, Van Geen et al. (2011) observed an inverse relationship between arsenic and microbial contamination, where wells with low arsenic more frequently contained *Escherichia coli*, especially during rainfall and in densely populated areas, demonstrating a risk substitution problem as households shift to low-arsenic wells but increase their exposure to microbial pathogens. Overall, these studies show that groundwater is not inherently safe and remains highly vulnerable to contamination from sanitation systems, shallow aquifers, industrial activities, and poorly protected wells, while advanced detection methods reveal hidden pathogens and antibiotic resistance that further intensify public health risks, highlighting the urgent need for improved well construction, site-specific risk assessment, and integrated monitoring of both chemical and microbial hazards.

Table 5. Environmental Risk Factors and Mitigation Strategies for Well Water Contamination

Country	Environmental Risk Factors Identified	Sanitation Conditions Around Wells	Mitigation Strategy Implemented	Reported Effectiveness	Author(s) & Year
Bangladesh	Shallow well depth and close proximity of wells to household latrines and wastewater drains	Limited sanitation infrastructure and poor well protection in rural communities	Chlorination of well water (maintaining ~0.5 mg/L residual chlorine)	Approximately 0.43 log CFU reduction in fecal bacteria and about 61% decrease in reported diarrheal cases	Rahman et al. (2019)
Thailand	Inadequate well construction, proximity to septic systems, and infiltration of surface runoff during rainfall	Moderate sanitation facilities but insufficient protective well structures	Well sealing, improved well lining, and community sanitation improvements	Significant reduction in fecal coliform levels after structural well improvements and sanitation interventions	Chai et al. (2021)
India	Unprotected dug wells, shallow groundwater depth, and contamination from domestic wastewater and nearby sanitation facilities	Mixed sanitation conditions with inadequate waste management in some rural areas	Household-level boiling of water and periodic water quality monitoring	Reduced microbial exposure through boiling; however, effectiveness not quantitatively reported in the study	Mukhopadhyay et al. (2012)
Indonesia	Agricultural runoff, groundwater infiltration, and poor waste management within the watershed	Sanitation systems insufficient to prevent groundwater contamination	Public awareness campaigns and improved groundwater management practices	Study reported increased risk awareness but limited measurable improvement in contamination levels	Kurniasari et al. (2026)
Philippines	Wells located within close distance to septic tanks and poor enforcement of sanitation buffer zones	Presence of multiple septic tanks within recommended groundwater protection zones	Enforcement of sanitation regulations, septic tank maintenance, and groundwater monitoring	Recommended measures expected to reduce contamination risk; quantitative effectiveness not reported	Garay & Sumaria (2025)

Vietnam	Flooding events and inadequate well protection allowing pathogen infiltration	Rural sanitation infrastructure limited in some communities	Installation of sanitary well caps and chlorination practices	Reported reduction of fecal contamination and decreased incidence of diarrheal illness in affected households	Nguyen et al. (2020)
Malaysia	Flood-prone environments causing contamination of groundwater wells after heavy rainfall	Sanitation infrastructure vulnerable to floodwater intrusion	Emergency chlorination and well disinfection following flood events	Approximately 0.9 log reduction in <i>E. coli</i> levels and decline in post-flood gastrointestinal illness cases	Ismail et al. (2018)
Cambodia	Shallow hand-dug wells and inadequate waste disposal near groundwater sources	Poor sanitation and limited protective well structures in peri-urban communities	Well lining reinforcement, sanitation improvements, and household filtration systems	Approximately 1.1 log reduction in fecal indicator bacteria and reduced incidence of pediatric diarrhea	Sokunthea et al. (2017)

Table 5 presents findings from this systematic review that consistently identify several environmental conditions contributing to microbial contamination of well water in Southeast Asia. One of the most commonly reported risk factors is how close wells are to sanitation facilities, especially household latrines and septic tanks. In Bangladesh and the Philippines, for instance, wells near these sanitation structures were found to be especially vulnerable to fecal contamination. This is due to wastewater seeping into shallow groundwater systems. Poor well protection and weak sanitation infrastructure also increase the chances that harmful microorganisms enter groundwater sources used for domestic consumption. These findings emphasize the need to keep wells at safe distances from potential contamination sources to reduce microbial risks. In addition to factors related to sanitation, hydrological and environmental conditions such as flooding, agricultural runoff, and shallow groundwater depth were also identified as major contributors to contamination. Studies in Malaysia and Vietnam showed that flood events can help transport microbial contaminants from surface sources into groundwater wells, especially when well protection is inadequate. Similarly, agricultural runoff and contamination at the watershed level were recognized in Indonesia as significant pathways for microbial and chemical pollutants entering groundwater systems. These environmental processes can greatly increase community exposure to contaminated drinking water, particularly in rural areas where wells are the main source of water for households. Several strategies have been implemented across the reviewed studies to lower the risks associated with contaminated well water. Chlorination was often cited as an effective method for reducing microbial contamination. In Bangladesh and Malaysia, measurable reductions in fecal indicator bacteria and related diarrheal cases were noted. Structural improvements such as well sealing, better well lining, and installing sanitary well caps also helped keep contaminated surface water out of groundwater wells. In Thailand and Cambodia, strengthening well infrastructure and enhancing nearby sanitation conditions led to noticeable declines in microbial contamination levels.

Household-level actions were also recognized as practical ways to reduce exposure to pathogens in contaminated water sources. In India, practices like boiling drinking water and regular water quality monitoring were recommended to minimize microbial risks, especially in communities where infrastructure upgrades may be slow. However, some studies mentioned that while these strategies can lower exposure, their success relies heavily on consistent implementation and community awareness. For example, in Indonesia, awareness campaigns boosted community understanding of water safety risks, but measurable reductions in contamination levels were limited due to ongoing environmental pressures. Overall, the findings of this review suggest that microbial contamination of well water in Southeast Asia is greatly influenced by environmental conditions, sanitation infrastructure, and groundwater protection efforts. Effective risk reduction, therefore, requires a thorough approach that combines better sanitation management, protective well construction, regular water quality monitoring, and community-driven water treatment practices. Strengthening these efforts is crucial for reducing exposure to waterborne

pathogens and safeguarding public health in communities that depend on groundwater wells as their main source of drinking.

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CONCLUSION

This systematic review comprehensively examined the microbiological contamination of well water across Asian countries, synthesizing evidence from multiple studies to assess contamination sources, health impacts, and mitigation strategies. The findings reveal a pervasive and significant public health crisis, with well water contamination prevalence ranging from 24% to 100% across studied regions, predominantly characterized by fecal indicator bacteria such as *Escherichia coli* and total coliforms.

The review demonstrates that groundwater sources throughout Asia are highly vulnerable to microbial contamination due to several interconnected factors. Shallow well depth, proximity to sanitation facilities (particularly within 10-25 meters), inadequate well construction and protection, and environmental conditions such as flooding and seasonal rainfall were consistently identified as primary risk factors. The evidence indicates that even protected wells and those in managed settings remain susceptible to contamination when sanitation infrastructure is insufficient or well siting regulations are poorly enforced.

A particularly concerning finding is the diversity and severity of pathogenic microorganisms detected across Asian well water systems. Beyond conventional fecal indicators, studies identified multiple bacterial pathogens including enterotoxigenic *E. coli* (ETEC), *Shigella* spp., *Vibrio cholerae*, *Aeromonas* spp., and *Staphylococcus aureus*, as well as viral pathogens (Rotavirus, Adenovirus) and protozoan parasites (*Giardia duodenalis*, *Cryptosporidium* spp.). The detection of multidrug-resistant bacteria in several studies, with Multiple Antibiotic Resistance (MAR) indices exceeding 0.2, raises additional public health concerns regarding the potential for waterborne transmission of antibiotic-resistant infections.

The health impacts associated with contaminated well water are substantial and disproportionately affect vulnerable populations, including children, the elderly, and immunocompromised individuals. Waterborne diseases such as diarrhea, gastroenteritis, cholera, typhoid, and hepatitis were consistently linked to microbial contamination, with quantitative microbial risk assessments revealing high annual infection probabilities and significant disability-adjusted life year (DALY) burdens. Notably, several studies demonstrated that conventional monitoring methods may underestimate true health risks, as advanced molecular techniques (ddPCR, DEUF) frequently detected pathogens even when standard culture methods indicated compliance with water quality guidelines.

Regarding mitigation strategies, this review identified several interventions with varying degrees of effectiveness. Chlorination consistently demonstrated measurable reductions in fecal bacteria (approximately 0.4-0.9 log reductions) and associated decreases in diarrheal disease incidence (up to 61% reduction). Structural improvements including well sealing, sanitary well caps, and improved lining effectively reduced contamination by preventing surface water infiltration. Household-level interventions such as boiling water and point-of-use treatment provided practical alternatives where infrastructure improvements were not immediately feasible. However, the effectiveness of these strategies depends heavily on consistent implementation, community awareness, and the capacity to address underlying environmental and sanitation challenges.

Importantly, this review reveals a critical risk substitution phenomenon, particularly illustrated in Bangladesh, where households switching to low-arsenic wells to avoid chemical exposure inadvertently increased their risk of microbial infection. This finding underscores the necessity of integrated water safety management approaches that simultaneously address both chemical and microbiological hazards rather than trading one risk for another.

The evidence synthesized in this review carries important policy implications. First, there is an urgent need for strengthened regulatory frameworks governing well construction, including mandatory minimum separation distances from sanitation facilities (with site-specific risk assessments recognizing that standardized distances

may be inadequate in dense urban settings). Second, regular water quality monitoring programs must be established or enhanced, incorporating both conventional indicator organisms and, where feasible, advanced pathogen detection methods to identify hidden risks. Third, integrated sanitation and water safety planning is essential, recognizing that groundwater protection cannot be achieved without concurrent improvements in sanitation infrastructure and waste management.

In conclusion, this systematic review demonstrates that microbiological contamination of well water represents a significant and ongoing public health challenge across Asia, driven by inadequate sanitation, poor well construction, environmental factors, and insufficient monitoring. The consistent classification of risk as high across diverse geographical and socioeconomic contexts underscores the urgent need for coordinated action. Effective risk reduction requires comprehensive strategies that combine improved well construction standards, enhanced sanitation infrastructure, regular water quality surveillance, household-level water treatment, and community engagement. Future research should focus on longitudinal studies to assess intervention effectiveness over time, investigate the ecological and health impacts of antibiotic-resistant bacteria in water systems, and develop context-specific risk assessment frameworks that account for the complex interplay of environmental, sanitary, and socioeconomic factors influencing well water quality in Asian communities.

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