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The Relationship Between Groundwater Quality and the Prevalence of Waterborne Diseases

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Abstract
Groundwater supplies drinking water to roughly half of the world's population, yet it is increasingly exposed to contamination from sewage, agriculture, industry, and natural geological sources. Waterborne diseases such as diarrhoea, typhoid, cholera, and hepatitis remain a major cause of illness and death, particularly among children in low- and middle-income countries. This study examines the relationship between groundwater quality and the prevalence of waterborne diseases. A systematic narrative review was conducted following PRISMA guidelines, using with reports from WHO, UNICEF, and UNEP. Studies reporting groundwater or well water quality and associated health outcomes were screened, and findings were grouped into contamination sources, microbial hazards, chemical hazards, modifying factors, and interventions. Groundwater quality was interpreted against the WHO Guidelines for Drinking-water Quality. The reviewed evidence shows a consistent association between faecal contamination of wells and boreholes and enteric disease, with outbreaks frequently following heavy rainfall and flooding. Arsenic, fluoride, and nitrate contribute to chronic health effects through long-term exposure. The strength of the relationship depends on aquifer depth and geology, sanitation coverage, well construction, and household water storage and handling. Interventions that protect wells, improve sanitation, and treat water at the point of use reduce disease risk. The findings highlight the need for routine groundwater monitoring, source protection, integrated water quality and health surveillance, and water safety planning. Protecting groundwater is therefore both an environmental priority and a public health necessity, and is central to achieving Sustainable Development Goal 6.

Keywords: Groundwater quality; Waterborne diseases; Faecal contamination; Drinking water; Public health.

1. Introduction

Groundwater is among the most important freshwater resources on Earth. It supplies drinking water to roughly half of the global population and a large share of irrigation water, especially in arid and semi-arid regions where surface water is scarce or seasonal (Morris et al., 2003). Because it is stored underground and filtered naturally through soil and rock, groundwater has long been considered safer than surface water. This assumption is increasingly challenged by evidence that aquifers are vulnerable to contamination from human activities and natural geological processes (Foster & Chilton, 2003; Lapworth et al., 2012).

Groundwater quality is shaped by both natural and anthropogenic factors. Naturally occurring contaminants such as arsenic, fluoride, and excess salinity can leach from aquifer minerals into water and cause chronic health problems (Smedley & Kinniburgh, 2002). Human activities, including poorly constructed septic systems, leaking sewage networks, open defecation, intensive agriculture, and industrial discharge, introduce pathogens, nitrates, pesticides, and other pollutants into aquifers. Shallow, unprotected wells and boreholes are especially at risk, since contaminants can migrate rapidly from the surface to the water table (Ashbolt, 2004 :Lamma, 2021).

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Waterborne diseases are illnesses caused by pathogenic bacteria, viruses, protozoa, and helminths transmitted through contaminated drinking water. They include cholera, typhoid fever, dysentery, hepatitis A and E, giardiasis, and cryptosporidiosis. Diarrhoeal disease remains a leading cause of illness and death worldwide, particularly among children under five. The World Health Organization estimates that unsafe water, sanitation, and hygiene are responsible for a substantial proportion of this burden, most of it in low- and middle-income countries (Prüss-Ustün et al., 2019; Wolf et al., 2023). A global review found that a significant share of the world's drinking water sources show faecal contamination, with the highest risks in rural areas and unprotected sources (Bain et al., 2014: Lamma, 2020).

The link between groundwater quality and disease is therefore direct and well documented. When aquifers are contaminated with faecal matter, communities that depend on wells or boreholes without adequate treatment are exposed to enteric pathogens, and outbreaks can follow. Contamination may also occur after collection, through unsafe storage and handling in the household (Wright et al., 2004). Chemical contaminants such as nitrate, arsenic, and fluoride, although not infectious, add to the public health burden through long-term exposure. Epidemiological evidence shows that improving water supply and quality can substantially reduce the incidence of diarrhoeal disease (Hunter et al., 2010: Lamma & Swamy, 2019).

The relationship is not uniform. It depends on aquifer depth and geology, rainfall and flooding, population density, sanitation coverage, well construction standards, and the presence of monitoring and treatment systems. Climate change, rapid urbanization, and over-extraction further threaten both the quantity and quality of groundwater, making these links more complex and more urgent to understand (Taylor et al., 2013).

This study examines the relationship between groundwater quality and the prevalence of waterborne diseases. It reviews the main sources of groundwater contamination, the pathogens and chemicals of public health concern, and the evidence connecting them to disease patterns. Understanding this relationship is essential for guiding groundwater monitoring, protecting aquifers, and designing effective public health interventions in line with the WHO Guidelines for Drinking-water Quality (WHO, 2017) and Sustainable Development Goal 6.

2. Problem Statement

Despite the widespread belief that groundwater is a safe source of drinking water, a large proportion of the world's population relies on wells and boreholes that are neither protected nor regularly monitored. In many regions, aquifers receive untreated wastewater, agricultural runoff, and industrial effluents, while natural contaminants such as arsenic and fluoride occur at concentrations above health-based guideline values (Smedley & Kinniburgh, 2002; Fawell et al., 2006). At the same time, waterborne diseases continue to cause hundreds of thousands of deaths every year, most of them among young children (Wolf et al., 2023:Lamma & Swamy, 2018.

The evidence linking groundwater quality and disease is scattered across disciplines. Hydrogeological studies describe contamination pathways but rarely report health outcomes, whereas epidemiological studies report disease rates but often treat the water source as a single "improved" or "unimproved" category without considering actual water quality (Bain et al., 2014; Wolf et al., 2014). This gap makes it difficult for decision makers to identify which contaminants, which aquifer conditions, and which communities carry the highest risk. The problem addressed by this study is therefore the lack of an integrated understanding of how groundwater quality, measured through microbiological and physico-chemical indicators, relates to the occurrence of waterborne diseases, and of which factors strengthen or weaken that relationship.

3. Research Objectives

The main objective of this study is to assess the relationship between groundwater quality and the prevalence of waterborne diseases. The specific objectives are:

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1. To identify the main natural and anthropogenic sources of groundwater contamination.
2. To describe the microbiological and chemical indicators used to evaluate groundwater quality for drinking purposes against WHO guideline values.
3. To summarise the evidence linking faecal and chemical contamination of groundwater to waterborne disease outbreaks and endemic disease burden.
4. To determine the environmental, hydrogeological, and socio-economic factors that modify this relationship.
5. To propose management and public health measures for protecting groundwater and reducing disease risk.

4. Research Questions

What are the principal sources and pathways of groundwater contamination?

1. Which microbial and chemical contaminants in groundwater are most strongly associated with human disease?
2. Is poorer groundwater quality associated with a higher prevalence of waterborne diseases such as diarrhoea, typhoid, cholera, and hepatitis?
3. How do well construction, aquifer depth, rainfall and flooding, sanitation coverage, and household water handling influence this association?
4. Which interventions are most effective in improving groundwater quality and reducing disease incidence?

5. Literature Review

5.1 Groundwater as a drinking water resource

Groundwater is the largest accessible reserve of liquid freshwater and the main source of drinking water for billions of people, particularly in rural settlements without piped supply (Morris et al., 2003). Foster and Chilton (2003) showed that aquifer degradation is a global concern, driven by urbanization, agricultural intensification, and over-abstraction, and that the slow movement of groundwater means pollution can persist for decades once it occurs.

5.2 Sources and pathways of contamination

Pedley and Howard (1997) described how on-site sanitation, leaking sewers, and livestock waste introduce faecal microorganisms into aquifers, with risk depending on soil type, depth to the water table, and distance between latrines and wells. In Kampala, Uganda, Howard et al. (2003) found that faecal indicator bacteria in shallow wells were associated with heavy rainfall, poor well protection, and the proximity of pit latrines. Lapworth et al. (2012) added that emerging organic contaminants, including pharmaceuticals and pesticides, are increasingly detected in aquifers worldwide.

5.3 Pathogens of public health concern

Cabral (2010) reviewed bacterial pathogens transmitted by water, including *Vibrio cholerae*, *Salmonella* Typhi, *Shigella* spp., and pathogenic *Escherichia coli*. Viruses such as hepatitis A and E and norovirus, and protozoa such as *Giardia* and *Cryptosporidium*, are also important because some are resistant to chlorine or travel long distances in groundwater. Ashbolt (2004) emphasised that infection depends on pathogen concentration, dose, and host susceptibility, and that children, the elderly, and immunocompromised people are at greatest risk.

5.4 Chemical contaminants

Non-infectious contaminants affect health through long-term exposure. Chronic arsenic ingestion is associated with skin lesions, cardiovascular disease, and cancers (Naujokas et al., 2013). Excess fluoride causes dental and skeletal fluorosis (Fawell et al., 2006). High nitrate concentrations, commonly caused by fertiliser use and sewage, are linked to methaemoglobinaemia in infants and have been associated with other adverse outcomes (Ward et al., 2018). WHO guideline values are 10 µg/L for arsenic, 1.5 mg/L for fluoride, and 50 mg/L for nitrate (WHO, 2017).

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5.5 Evidence linking water quality and disease

Systematic reviews show that the type and quality of the water source matter. Bain et al. (2014) found faecal contamination in a substantial share of sources in low- and middle-income countries, including sources classified as improved. Wolf et al. (2014) found that interventions improving water quality, especially at the point of use, reduced diarrhoeal risk in such settings. Hunter et al. (2010) concluded that improvements in water supply and quality lower the burden of diarrhoeal disease. Curriero et al. (2001) demonstrated that extreme rainfall was associated with waterborne disease outbreaks in the United States, supporting the role of weather events in mobilising contaminants into water sources. Wright et al. (2004) showed that water often becomes contaminated between the source and the point of use, so that source quality alone does not determine health outcomes.

5.6 Research gap

Previous work establishes the general association, but few studies combine groundwater quality indicators, hydrogeological conditions, and health outcomes within a single framework. This study seeks to synthesise these elements.

6. Materials and Methods

6.1 Study design

This study uses a systematic narrative review design supported by a conceptual framework linking contamination sources, groundwater quality, human exposure, and disease outcomes (Figure 1). The review was structured following the PRISMA guidelines for transparent reporting (Moher et al., 2009).

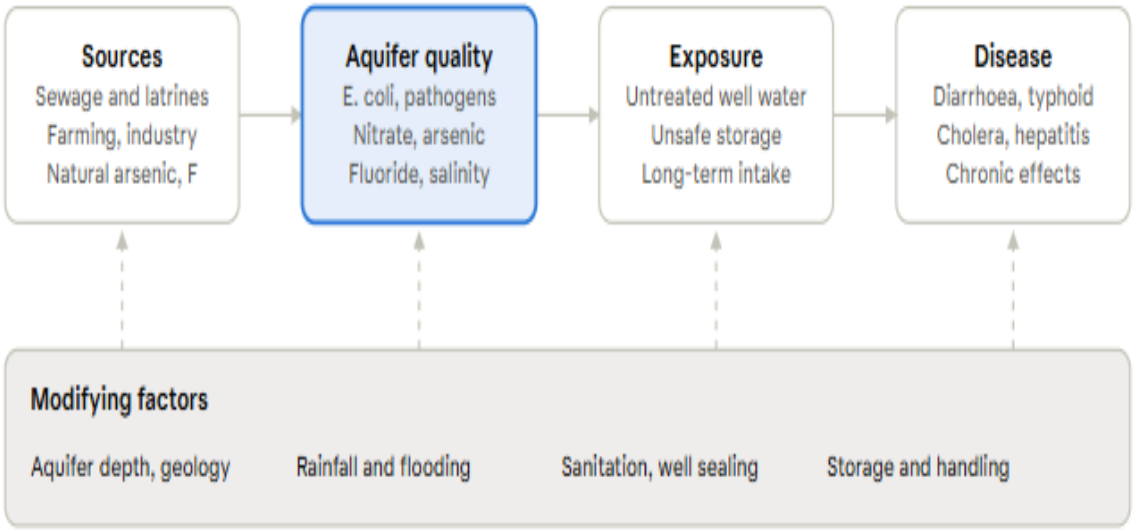


Figure 1. Conceptual framework linking contamination sources, groundwater quality, human exposure, and waterborne disease. Modifying factors act on every stage.

6.2 Data extraction and analysis

For each included study, the following were extracted: location, type of water source, contaminants measured, analytical methods, health outcome, and main findings. Findings were grouped into themes (contamination sources, microbial hazards, chemical hazards, modifying factors, and interventions) and compared qualitatively. Groundwater quality was interpreted against the WHO Guidelines for Drinking-water Quality (WHO, 2017), which require the absence of *E. coli* in 100 mL of drinking water.

7. Results

7.1 Sources of groundwater contamination

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The reviewed literature identifies five main groups of contamination sources: on-site sanitation and leaking sewers, livestock and agricultural activities, industrial and mining discharges, natural geogenic sources, and intrusion of saline or polluted water caused by over-abstraction (Foster & Chilton, 2003; Pedley & Howard, 1997; Smedley & Kinniburgh, 2002). Shallow and poorly protected wells were consistently reported as more vulnerable than deep, sealed boreholes (Howard et al., 2003).

7.2 Microbial and chemical hazards

Faecal indicator bacteria were the most frequently reported quality problem in studies of household and community wells, and their presence was most common after heavy rainfall and where latrines were close to the well (Howard et al., 2003; Bain et al., 2014). The main chemical hazards were arsenic, fluoride, and nitrate, each of which has a recognised long-term health effect (Naujokas et al., 2013; Fawell et al., 2006; Ward et al., 2018). Table 1 summarises the WHO health-based guideline values for these chemical parameters.

Table 1. WHO health-based guideline values for key drinking-water contaminants (WHO, 2017)

Contaminant	Guideline value	Main health effect
Arsenic	10 µg/L	Skin lesions, cancers, cardiovascular disease
Fluoride	1.5 mg/L	Dental and skeletal fluorosis
Nitrate	50 mg/L	Methaemoglobinaemia in infants
E. coli	Not detectable in 100 mL	Faecal contamination, enteric infection

7.3 Association with waterborne disease

Across the reviewed studies, poorer microbiological quality of drinking water was associated with higher rates of diarrhoea and enteric infection, and outbreaks of cholera, typhoid, and hepatitis were repeatedly traced to contaminated wells and untreated supplies (Hunter et al., 2010; Cabral, 2010). At global level, unsafe water, sanitation, and hygiene were estimated to account for around 1.4 million deaths in 2019 (Wolf et al., 2023), and Bain et al. (2014) estimated that about 1.8 billion people use a drinking water source contaminated with faeces. The burden is concentrated in low- and middle-income countries and among children under five.

7.4 Modifying factors

Four groups of factors modified the strength of the relationship: (1) hydrogeological conditions such as aquifer depth, soil permeability, and recharge; (2) climatic events, with extreme rainfall and flooding raising the likelihood of outbreaks (Curriero et al., 2001); (3) sanitation coverage and well construction standards; and (4) household storage and handling, which can add contamination after collection (Wright et al., 2004). Climate change and groundwater depletion were reported to increase future risk (Taylor et al., 2013).

7.5 Effectiveness of interventions

Interventions that protect wells, improve sanitation, and treat water, particularly at the point of use through chlorination, filtration, or boiling, were associated with reduced diarrhoeal disease (Wolf et al., 2014; Hunter et al., 2010).

Discussion

The findings support the view that groundwater is not inherently safe, and that its quality is a direct determinant of waterborne disease risk. The consistent association between faecal contamination and enteric disease is biologically plausible: pathogens excreted by infected people and animals reach shallow aquifers through poorly sited latrines and leaking sewers, and are then ingested when untreated water is consumed (Pedley & Howard, 1997; Ashbolt, 2004). The finding that sources classified as improved can still be contaminated (Bain et al., 2014) shows that source type is a weak proxy for safety and that routine water quality testing is needed.

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The role of rainfall and flooding explains why disease incidence is often seasonal and why outbreaks follow extreme weather (Curriero et al., 2001). Under climate change, more intense rainfall and prolonged drought may both degrade groundwater quality, the former by flushing contaminants into aquifers and the latter by concentrating salts and encouraging deeper, riskier abstraction (Taylor et al., 2013). Chemical contaminants differ from microbial ones in that their effects appear after years of exposure, so they are less visible in outbreak records and are likely under-recognised in public health statistics (Naujokas et al., 2013).

The evidence on post-collection contamination (Wright et al., 2004) implies that protecting the aquifer is necessary but not sufficient, and that household water treatment and safe storage complete the protective barrier. This is consistent with the multiple-barrier approach and water safety plans recommended by WHO (2017).

Several limitations should be noted. Many studies use different indicators, sampling frequencies, and health outcome definitions, which limits direct comparison. Most studies are cross-sectional and show association rather than causation, and confounding factors such as hygiene practices and nutrition are not always controlled. The narrative review design also does not provide a pooled effect size. Future research should combine repeated groundwater sampling with health surveillance data in the same communities.

Conclusion

The evidence reviewed shows a clear and consistent relationship between groundwater quality and the prevalence of waterborne diseases. Faecal contamination of wells and boreholes is a major driver of diarrhoeal disease, typhoid, cholera, and hepatitis, while arsenic, fluoride, and nitrate contribute to chronic health problems. The strength of the relationship depends on aquifer vulnerability, rainfall and flooding, sanitation coverage, well construction, and household water handling. Improving source protection, sanitation, monitoring, and treatment reduces disease risk. Protecting groundwater quality is therefore both an environmental priority and a public health necessity, and is central to achieving Sustainable Development Goal 6.

Recommendations

Establish routine groundwater monitoring programmes that test for faecal indicator bacteria and priority chemicals (arsenic, fluoride, nitrate) against WHO guideline values.

1. Protect wells and boreholes through sanitary sealing, drainage, fencing, and minimum safe distances from latrines, septic tanks, and livestock areas.
2. Expand sanitation and wastewater management to prevent contamination at source, particularly in densely populated and rural areas.
3. Promote household water treatment and safe storage, including chlorination, filtration, and boiling where the supply is not reliably safe.
4. Develop water safety plans and early-warning systems linked to rainfall and flood events.
5. Integrate water quality data with health surveillance so that outbreaks can be detected and traced to their source quickly.
6. Regulate agricultural, industrial, and mining activities that threaten aquifer quality, and manage abstraction to avoid saline intrusion and aquifer depletion.
7. Support further research that combines hydrogeological, microbiological, and epidemiological data in the same study areas, and raise community awareness of groundwater protection and hygiene.

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