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Impact and interventions of waterborne and foodborne illnesses caused by bacterial pathogens in Nigeria: A review

Chidinma A. OKAFOR

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Godfrey Okoye University, Department of Biological Sciences, Enugu, Nigeria

ORCID IDs of the authors:
C.A.O. 0000-0003-2700-5306

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Correspondence:
Chidinma A. OKAFOR
E-mail: okaforca@gmail.com

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ABSTRACT

Waterborne and foodborne illnesses caused by bacterial pathogens are major public health concerns, especially in developing countries like Nigeria—waterborne pathogens such as *Escherichia coli, Salmonella* spp. and *Klebsiella* spp. Contribute to the spread of health challenges, primarily due to poor sanitation, contaminated drinking water, and inadequate hygiene. Similarly, foodborne pathogens, including *Escherichia coli, Listeria monocytogenes* and *Salmonella* spp., are major causes of human illness, with animal-based foods often acting as transmission vectors. This review examines the current state of diagnosis, highlighting that most household water sources in Nigeria are vulnerable to contamination, with significant microbial loads exceeding WHO standards. It raises the need for effective interventions such as improved hygiene practices, water supply, sanitation and food safety management systems. Furthermore, this review discusses the impact of these pathogens on public health, noting that waterborne and foodborne diseases result in substantial mortality and economic burdens. Also, implementing good hygienic practices, Hazard Analysis Critical Control Point (HACCP) systems, and public health education are essential strategies for reducing the incidence of these diseases. This review concludes by calling for a collaborative effort among governments, policymakers, stakeholders, and researchers to develop and implement multifaceted interventions to combat these pervasive health threats.

Keywords: Waterborne illness, Foodborne pathogen, Public health, Contamination, Interventions

Introduction

Waterborne illnesses are health problems caused by consuming water contaminated with disease-causing microbes or pathogens. These pathogens are transmitted directly to humans when contaminated water is used for drinking, bathing, washing, and cooking (Meki et al., 2022). *Salmonella* spp*., Escherichia coli, Klebsiella* spp*., Proteus mirabilis, and Enterobacter* spp. are some bacteria associated with waterborne diseases (Iwuala et al., 2018). The problems encountered with drinking water in some parts of Nigeria have raised public health concerns. According to the World Health Organization, over 2.6 billion people lack access to safe drinking water, which causes approximately 2.2 million deaths each year, 1.4 million of which are children (WHO, 2023; Nwabor, 2016). In another report, the United Nations Department of Economic and Social Affairs -UNDESA (2019) estimated that nearly 900 million people worldwide cannot access safe drinking water. Despite numerous efforts by various levels of government and other organisations interested in water and its safety, waterborne diseases remain a major public health and environmental concern.

Foodborne microorganisms are major pathogens that affect food safety and cause human illness worldwide. Bacteria cause two-thirds of human foodborne diseases worldwide, with a disproportionate burden in developing countries like Nigeria (Gugsa & Meselu, 2020; Etinosa et al., 2021). Food from animals is the primary reservoir of many foodborne bacterial pathogens, and animal-derived foods are the main transmission vehicles. *Staphylococcus aureus, Salmonella* spp*., Campylobacter* spp*., Listeria monocytogenes, and Escherichia coli* are the most common bacterial pathogens that cause foodborne illness and death worldwide when contaminated animal products are consumed (Bintsis, 2017; Oduori et al., 2022; WHO, 2022). Human infections caused by these major bacteria are characterised by gastrointestinal symptoms such as nausea, vomiting, diarrhoea, abdominal cramps, and other agent-specific symptoms (Odeyemi, 2016). Some strains can lead to serious complications or even death (WHO, 2022).

Current State of Diagnosis

State of Diagnosis for Waterborne Illnesses

At all economic levels, drinking water has a well-documented history of spreading microbial infections to large populations and inflicting disease. For instance, Cholera is a waterborne illness influenced by rainfall, drought, and global climate events, with a high ability to be transferred from one person to another. Its epidemiology begins in endemic areas and expands to congested slums and refugee camps, with human displacement being a significant factor in its spread from one location to another (Rebaudet, 2013). Unimproved water supply, poor sanitation, faecal contamination, limited level of education for caregivers, improper hygiene, and climate change are major factors responsible for such poor water quality in developing countries and the spread of illness (Cissé, 2019; Adamu et al., 2020). Also, the microbiological quality of household drinking water in Enugu City and Delta State, Nigeria, showed unsafe standards for drinking (Ocheli et al., 2020; Okpasuo et al., 2020). For instance, *Escherichia coli* (38.0%), *Giardia lamblia* (35.2%), *Entamoeba histolytica* (33.0%), *Salmonella typhi* (19.9%), *Proteus* spp. (13.2%), *Shigella dysentery* (9.4%), *Klebsiella spp*. (7.4%), *Enterobacter spp*. (5.5%), and *Cryptosporidium spp*. (5.2%) were found in 344 (85.4%) of the 403 samples collected from stool, using a cross-sectional multi-stage sampling design across Enugu State, Nigeria (Okpasuo et al., 2020). Table 1 presents major waterborne and foodborne pathogens that cause illness. Transmission ways for waterborne pathogens include consumption of contaminated water, recreational activities such as swimming in contaminated pools, lakes, rivers, or oceans, inadequate sewage disposal and lack of proper sanitation facilities, runoff from agricultural fields carrying pathogens, improper storage and handling of water, climate and environmental factors like heavy rains, floods, and natural disasters (Shanmugam et al., 2024). Radiopharmaceutical and medical waste also pose risks to soil and water contamination, affecting plants and food products (Cetinkaya, 2024). Seasonal factors affecting biological contamination include microbial contamination of groundwater, which was higher in the dry season than in the wet season (Ocheli et al., 2020).

According to the findings, most household water sources are vulnerable to contamination at multiple points along their journey from source to mouth (Okpasuo et al., 2020). Except for a few locations in Okigwe (sachet water 1%) and Orlu zone (borehole 2%), most drinking water sources in Imo state, Nigeria, had bacterial loads exceeding WHO standards of zero total coliform colonies/100 mL (Okpasuo et al., 2020). The study area had a significant relationship between water quality and hospital records of waterborne illness (Iwuala et al., 2018). Similar findings were observed in Sokoto, Shuni, and Tambuwal (Nwabor et al., 2016). Water samples from 96% of the wells in Ibadan Municipal City were found to be contaminated with both total and faecal coliform counts ranging from 0 to $160x10^3$/100 ml and 0 to $22x10^3$/100 ml, respectively (Odeleye & Idowu, 2015).

Table 1. Major waterborne and Foodborne Pathogens that cause Illness in Nigeria

Bacterial Pathogens	Illnesses	Sources	References
		Waterborne	
Escherichia coli	Diarrhoea, urinary tract infections, respiratory illness, and pneumonia	Contaminated water, food, and direct contact with infected animals or people	Okpasuo et al., 2020; WHO, 2022
Salmonella spp.	Typhoid fever, paratyphoid fever, and salmonellosis	Contaminated water, food (especially poultry, eggs, and dairy products)	Heredia and Garcia, (2018). WHO, 2022
Vibrio cholerae	Cholera	Contaminated water, seafood, and other foods.	Rebaudet, 2013; WHO, 2022
Giardia lamblia	Giardiasis	Contaminated water, food, and surfaces	Okpasuo et al., 2020
Cryptosporidium spp.	Cryptosporidium spp.	Contaminated water, food, and surfaces	Okpasuo et al., 2020; WHO, 2022
Shigella spp.	Shigellosis (bacillary dysentery)	Contaminated water, food, and person-to-person contact	Nwabor et al., 2016
		Foodborne	
Salmonella spp.	Salmonellosis, typhoid fever	Contaminated food, especially poultry, eggs, and dairy products	Heredia and Garcia, (2018). WHO, 2022
Escherichia coli	Diarrhoea, urinary tract infections, respiratory illness, and pneumonia	Contaminated food, water, and direct contact with infected animals or people	Odeyemi, 2016; WHO, 2022
Campylobacter spp.	Campylobacteriosis	Contaminated food, particularly raw or undercooked poultry, unpasteurised milk, and untreated water	WHO, 2022
Listeria monocytogenes	Listeriosis	Contaminated food, especially dairy products, deli meats, and smoked fish	Bintsis, 2017; Oduori et al., 2022
Norovirus	Gastroenteritis	Contaminated food, water, and surfaces	WHO, 2022
Staphylococcus aureus	Staphylococcal food poisoning	Contaminated food, particularly those that are improperly stored or handled	Bintsis, 2017
Bacillus anthracis	Enteritis	Contaminated food, particularly rice and other starchy foods that are left at room temperature for too long	Ghareeb and Ali, 2023

Waterborne pathogens originate from several sources, including animal excretions, human and livestock faecal wastes, and contaminated food products. Animal excretions serve as a significant reservoir for zoonotic pathogens like *Bacillus anthracis, Campylobacter jejuni, Escherichia coli, Salmonella enterica,* and *Vibrio cholera*, which can lead to severe infections when transmitted through water (Ghareeb & Ali, 2023). Human, industrial, agricultural and livestock faecal wastes, often due to failing septic systems or improper manure management, can contaminate groundwater with microbial pathogens, necessitating the testing of water samples for microbial indicators as a warning sign of potentially pathogenic microorganisms (Danilova, 2020). Additionally, contaminated food products can harbour pathogens such as *Escherichia coli, Listeria monocytogenes, Salmonella, Shigella, Adenovirus, and Cryptosporidium*, emphasising the need for innovative pathogen detection techniques and stringent food safety management in the industry (Dimitrakopoulou et al., 2024). Environmental reservoirs like water, river, lake, and water-related devices can also harbour antimicrobial-resistant bacteria, including *Pseudomonas aeruginosa, Mycobacterium* spp, and *Legionella* spp, highlighting the importance of surveillance strategies to prevent healthcare-associated infections (Hayward et al., 2020).

State of Diagnosis for Foodborne Illnesses

Several pathogens have been identified as causing foodborne illnesses, with the most common pathogenic bacteria being *Escherichia coli, Salmonella* spp.*, Campylobacter* spp.*, Listeria* spp.*,* and *Enterobacteria* spp*. Listeria monocytogenes* are found in unpasteurised dairy products and various ready-to-eat foods (Laslo & Gyorgy, 2019; Oduori et al., 2022). For instance, *Salmonellosis* outbreaks are caused by raw milk, raw or undercooked poultry, and contaminated drinks (Heredia & Garcia, 2018). The occurrences of *Vibrio Cholera* are linked to rice, vegetables, millet gruel, and various types of seafood (Bintsis, 2017; WHO, 2022). Transmission ways for foodborne pathogens can occur through contaminated raw ingredients, improper cooking, cross-contamination, poor food storage, unhygienic food handling, use of contaminated water, improper preservation, and infected food handlers (Shanmugam et al., 2024). Furthermore, the World Health Organization estimates that foodborne pathogens kill more than 200,000 people in Nigeria each year due to improper processing, preservation, and service (Ibginosa, 2021). Therefore, contaminated drinking water and poor food handling practices cause microbial infections, health issues, and high mortality rates due to inadequate sanitation, poor hygiene, and climate change.

Impact on Public Health

Impact of Waterborne Illnesses on Public Health

According to WHO (2022), 5.8 billion people will use safely managed drinking water services in 2020 because many water sources have been improved and are contamination-free. Bacterial pathogens cause the spread of diseases such as cholera, diarrhoea, dysentery, hepatitis A, typhoid, and polio; these health risks are preventable. Each year, it is estimated that 505,000 people die from diarrhoea caused by unsafe drinking water, poor sanitation, and poor hygiene (WHO, 2022). However, diarrhoea is largely preventable, and 297,000 children under five could be saved each year if these risk factors were addressed (WHO, 2022). Two thousand twenty-one more than 251.4 million people needed schistosomiasis prevention treatment, an acute and chronic disease caused by parasitic worms contracted through contact with infected water (WHO, 2022). For instance, residents of Yenagoa, Nigeria, have limited access to clean water, which predisposes them to diarrhoea and typhoid diseases, of which more cases were reported during the dry season (Ohwo & Omidiji, 2021). Other waterborne illnesses include skin and infectious eye illnesses like trachoma. Trachoma can cause vision loss or blindness, and rural populations, children, elders and health-challenged individuals are at a higher risk.

Impact of Foodborne Illnesses on Public Health

The rising mortality rate associated with preventable foodborne illnesses is a major concern, as it disproportionately affects infants, young children, adults and sick people. According to a World Health Organization (WHO) report, 550 million people become ill and die each year as a result of diarrheal diseases caused by eating foods contaminated with microbial pathogens (WHO, 2022). The overall productivity loss caused by foodborne diseases in developing countries is estimated to cost $95.2 billion annually, with approximately $15 billion spent on treating foodborne illnesses (WHO, 2023). Nigeria has the highest burden of foodborne illness in the AFR D subregion, with 1276 (459-2263) Disability Adjusted Life Years (DALYs) per 100,000 populations (Oduori et al., 2022). In Nigeria, stunting and malnutrition are prevalent in children under the age of five, with prevalence rates of 36.8% and 8.9%, respectively (National Population Commission (NPC), 2019). In developing countries, bacterial and parasitic diseases are associated risk factors with malnutrition.

Intervention

Interventions of waterborne illness

In accordance with SDG 6 - Clean Water and Sanitation, statistically, according to the World Health Organization (2010), these intervention practices can prevent 94% of waterborne diarrheal cases. Water supply, sanitation, hand washing, household water treatment, and safe storage reduce diarrhoea by 25%, 32%, 45%, and 39%, respectively (Manetu & Karanja, 2021). Other intervention methods include organising waterborne disease sensitisation campaigns, collaborating with health organisations to support the Nigerian government directly, and reducing unsafe drinking water and waterborne illnesses in Nigeria (Adeyinka et al., 2014). Regular monitoring of drinking water using quality indicators is essential for reducing public health hazards.

Meki et al. (2022) discovered that using 2 doses of cholera vaccines, an adequate potable water supply and safe storage, household disinfection, point-of-use chlorination, and hygiene improvement are effective methods for controlling cholera outbreaks. Therefore, interventions should be specific. Furthermore, in Ile-Ife, Nigeria, it was discovered that most cases were caused by poor sanitation, with most residents using open-pit toilets and living near market centres where large amounts of waste were generated and improperly disposed of in nearby streams. Therefore, separating human waste from drinking water is paramount (Manetu & Karanja, 2021).

WHO collaborates closely with UNICEF on various water and health issues, including water, sanitation, and hygiene in healthcare facilities. WASH FIT (Water and Sanitation for Health Facility Improvement Tool) aims to help small, primary healthcare facilities in low- and middle-income areas through a continuous cycle of improvement that includes risk assessments, risk prioritisation, and the creation of specific, targeted actions (WHO, 2022).

Good hygienic practices and Hazard Analysis Critical Control Point (HACCP) systems are essential tools in mitigating waterborne illness by identifying possible risks and implementing proper disposal of waste and sewage to prevent contamination of water sources and food, ensuring access to clean and safe drinking water by treating water sources with filtration, chlorination, or boiling; regular monitoring of water quality to detect and address contamination promptly (Onu et al., 2024). Alternative methods and technologies for interventions can also be implemented, such as boiling, household slow sand filters, filtration and preventive strategies for water management (Ocheli et al., 2020).

Intervention of foodborne illnesses

The control and prevention of foodborne illness can be achieved through good hygienic practices (GHPs), sanitation in operating procedures, and the implementation of standardised Hazard Analysis Critical Control Points (HACCP) and pasteurisation procedures in food processes (Bintsis, 2017; Etinosa et al., 2021). The emergence of multidrug-resistant bacteria associated with consuming contaminated animal products is currently a major public health concern, and there should be a coordinated surveillance and monitoring system for foodborne bacterial pathogens, particularly in developing countries such as Nigeria (Gugsa & Meselu, 2020). Food safety management systems are currently being developed to estimate the risks to human health posed by food consumption and to identify, select, and implement mitigation strategies for controlling and reducing these risks (Odeyami, 2016). Furthermore, applying appropriate food safety education programs for everyone involved in food production and consumption is critical to actualizing SDGs target 2 – Zero hunger.

Good hygienic practices and HACCP models are significant means of fostering foodborne pathogens through regular handwashing with soap and clean water, especially before handling food and after using the toilet, ensuring food handlers are free from infectious diseases and have access to clean clothing and protective gear; regular cleaning and disinfecting of food preparation and storage areas; keeping raw and cooked foods separate to prevent cross-contamination; cooking food to appropriate temperatures to kill harmful pathogens; storing food at safe temperatures to prevent the growth of bacteria (Dimitrakopoulou et al., 2024; WHO, 2023).

Comprehensive management plans should also aim to assess and identify vulnerable populations at risk of waterborne and foodborne illnesses. It involves conducting baseline surveys, mapping high-risk areas, improving water quality through infrastructure development, and implementing water treatment programs. Regular testing and testing ensure compliance with WHO standards. Enhancement of food safety involves safe food handling practices, training programs, and regular inspections. Education and awareness campaigns are launched to promote hygiene, safe water, and food practices (Onu et al., 2024). Healthcare interventions include improved access to medical care, vaccination programs, and antimicrobial stewardship. Emergency response and contingency planning involve developing contingency plans for rapid response to disease outbreaks, establishing early warning systems, and training community health workers. Collaboration and partnerships with government agencies, Non-Governmental Organizations (NGOs), and international bodies are encouraged. Community involvement is encouraged to foster a sense of ownership and responsibility. Sustainable practices include environmental management, waste management, and long-term monitoring (Hayward et al., 2020). By implementing this comprehensive management plan, vulnerable populations can be better protected from waterborne and foodborne illnesses, improving overall health and well-being.

Conclusion

In conclusion, waterborne and foodborne illnesses caused by bacterial pathogens pose significant public health challenges, especially in developing countries like Nigeria. Contaminated water and food sources cause cholera, typhoid, and foodborne infections. Infrastructure development, regular testing, and community-based programs are essential to manage these illnesses. Food safety can be enhanced through proper handling, regulations, and inspections. Education, awareness campaigns, and healthcare interventions are crucial. Collaboration between government agencies, NGOs, policymakers, stakeholders, researchers, the general public and international organisations is essential. Rapid methods like biosensors for detecting pathogens are also needed, alongside human capacity development in cutting-edge technologies and detection methods.

Compliance with Ethical Standards

Conflict of interest: The author(s) declares that they have no actual, potential, or perceived conflict of interest for this article.

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