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Assessment of groundwater contamination from septic tanks in low-income communities: implications for sustainable water and sanitation infrastructure

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ABSTRACT

Groundwater serves as the primary source of potable water for millions in Nigeria, particularly in low-income communities lacking centralized water and sanitation services. However, the widespread use of on-site sanitation systems, especially septic tanks sited too close to wells and boreholes, poses a persistent threat to groundwater quality. Numerous studies report elevated levels of microbial contaminants such as Escherichia coli and faecal coliforms, as well as nitrates, phosphates, and heavy metals in groundwater near poorly managed septic tanks. The contamination problem is exacerbated by substandard construction, inadequate maintenance, high population density, and weak regulatory oversight. Seasonal factors, such as increased recharge during the rainy season, further intensify pollutant migration, leading to frequent outbreaks of waterborne diseases, including cholera and typhoid. Vulnerable populations, especially children face increased risks of gastrointestinal and developmental disorders. Addressing this challenge requires an integrated approach: enforcing minimum setbacks of 30 meters between septic tanks and water sources, routine tank maintenance, groundwater monitoring, and the adoption of alternative sanitation solutions like decentralized wastewater treatment and ecological sanitation. Community engagement, participatory risk mapping, and education are vital for long-term behavior change. Cross-sectoral collaboration among government, NGOs, and stakeholders, supported by robust policy and sustained investment, is essential for achieving resilient and sustainable water and sanitation systems in Nigeria's vulnerable communities. This study underscores the urgent need for holistic interventions aligned with Sustainable Development Goal 6, to ensure safe water and sanitation access for all.

Keywords: *Ground water, Contamination, Septic tank, Low-income communities, and Sanitation infrastructure*

1. Introduction

Groundwater is the primary source of potable water for millions in Nigeria, especially among low-income communities lacking centralized water and sanitation infrastructure [1-3]. In these contexts, on-site sanitation such as septic tanks and pit latrines are often sited too close to wells and boreholes, posing a continuous threat to groundwater quality [1]. Multiple studies report elevated concentrations of microbial contaminants, including faecal coliforms and *Escherichia coli*, alongside nitrate, phosphate, and heavy metals in water samples collected near sanitation systems [2] For instance, Egbueri [12] found that over 60% of wells within 15 meters of septic tanks in Anambra State had nitrate above World Health Organization limits. In Lagos, Bello et al. [10] linked frequent outbreaks of waterborne diseases such as cholera and typhoid directly to groundwater contamination in informal settlements. This mounting evidence highlights an urgent need to address contamination from sanitation systems as a public health and sustainable development priority [3].

Research across Nigeria's ecological zones underscores the widespread and systemic nature of the problem. In Rivers State, Chima et al. [11] established that groundwater from boreholes near septic tanks exhibited excessive acidity and microbial contamination, while Oyetibo et al. [29] used geophysical imaging to track the migration of leachates. Ogunbode et al. [23] showed that improper management of hand-dug wells in Ibadan exposes residents to significant health hazards, with up to 85% of sampled wells failing to meet safety standards. In Bayelsa, Ogboe et al. [21] revealed the subsurface movement of sewage plumes through sandy soils, confirming that local hydrogeology amplifies groundwater vulnerability. Adeyemi et al. [5] in Lagos and Opara et al. [27] in Imo State found that contamination levels peak during the rainy season, when increased recharge enhances pollutant migration. The Niger Delta region is further affected by the compounded impacts of oil industry activity and poor sanitation, as detailed by Udensi et al. (2021). Furthermore, Adekoya et al. [1] and Eze et al. [14] revealed that both chemical and microbial contaminants routinely exceed national and international standards in peri-urban and rural communities.

The mechanisms and health risks associated with septic tank-related groundwater contamination have become clearer through recent studies. Acidic groundwater can mobilize heavy metals, especially in areas where septic effluent interacts with lateritic soils [24-26].

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Taiwo et al. [31] identified significant health risks from metals and metalloids in groundwater near market sanitation facilities, while Idehen and Nnaemeka [23] found nitrate, iron, and manganese were frequently above WHO guidelines in Benin City. Seasonal variability is also a critical factor, as highlighted by Bello et al. [10] and Ogboe et al. [21], who found that wet seasons intensify contamination risk. Risk assessments by Afolabi et al. [7] and Salisu et al. [30] indicate high probabilities of gastrointestinal and neurological diseases among children in affected communities. Notably, Aralu et al. [9] found polycyclic aromatic hydrocarbons (PAHs) from dumpsites co-contaminating groundwater with septic leachate, compounding health hazards.

Mitigating septic tank-related groundwater contamination in low-income Nigerian communities demands a multifaceted, context-sensitive approach. Enforcing a minimum 30-meter setback between septic systems and water sources is critical, as emphasized by Chima et al. [11] and Oyetibo et al. [29]. Integrating groundwater monitoring, regular septic tank maintenance, and low-cost water treatment, such as point-of-use filtration are vital steps [12, 13]. Community education, participatory risk mapping, and local stakeholder empowerment are essential for behavior change [5, 6]. Moreover, geo-environmental tools and microbial source tracking can identify contamination hotspots, guiding targeted interventions [7-9]. These strategies align with Sustainable Development Goal 6, which advocates for safe and inclusive water and sanitation access. Nigeria's experience underscores the need for cross-sectoral collaboration, robust policy, and persistent investment to achieve resilient water and sanitation systems in vulnerable settings [12-15].

2. Overview of Groundwater Use and Sanitation in Nigeria

Water and sanitation are foundational to public health, socioeconomic development, and environmental sustainability. In Nigeria, the largest country in Africa by population, the challenge of providing safe, adequate, and sustainable water and sanitation services is especially acute [32]. Rapid population growth, urbanization, weak infrastructure, and persistent poverty have strained existing water supply systems and sanitation networks, leading to widespread reliance on groundwater and on-site sanitation, particularly in low-income and informal settlements [17].

Groundwater stored beneath the earth's surface in aquifers has emerged as a crucial source of safe drinking water for both rural and urban communities [15]. Nigeria's surface water resources, including rivers, lakes, and reservoirs, are increasingly unreliable due to seasonal variability, pollution, and overuse. As a result, groundwater now supplies more than 60% of the nation's potable water needs, with even higher dependency in rural regions [15-17]. However, this heavy reliance brings its own risks: over-extraction, contamination from inadequate sanitation, and weak regulatory oversight threaten both water quality and long-term sustainability [1, 15].

Sanitation practices across Nigeria remain highly diverse and, in many cases, inadequate. While urban centers may offer limited access to sewered or improved sanitation, the vast majority of Nigerians especially those living in low-income or informal settlements, depend on basic onsite solutions such as pit latrines, septic tanks, and open defecation [24-27]. These practices, combined with high population density and poor infrastructure, pose serious risks of groundwater contamination and waterborne disease outbreaks.

2.1 Significance of Groundwater in Urban and Rural Water Supply

Nigeria's groundwater resources are extensive, with major aquifers underlying much of the country's territory. Their use is shaped by demographic, economic, and environmental variables. Rural communities, often neglected by centralized water supply schemes, depend almost exclusively on groundwater accessed through hand-dug wells, boreholes, and springs [15, 16, 20]. In many areas, up to 80% of households rely on these sources for drinking, cooking, and other domestic activities [5, 6, 17].

Urban areas, facing the dual pressures of rapid growth and deteriorating public infrastructure, have also become increasingly reliant on groundwater. For example, Lagos, Nigeria's largest city, is supplied by a municipal system that meets less than 10% of total demand, forcing most households and businesses to turn to private boreholes or water vendors [1, 12, 17]. Port Harcourt, Kano, and Ibadan exhibit similar trends, with groundwater meeting the majority of water needs for both residential and commercial users [15-17].

Industrial and agricultural sectors also depend heavily on groundwater. In the northern dry belt, groundwater is essential for year-round irrigation, livestock watering, and food processing [1, 23]. The relative stability of groundwater supplies during periods of drought or surface water scarcity has made it a vital resource for climate resilience [14]. However, unregulated groundwater abstraction is leading to falling water tables, higher drilling costs, and, in coastal regions, saltwater intrusion [12-14]. The lack of comprehensive monitoring and poor enforcement of drilling standards exacerbate these risks [33-35].

2.2 Common Sanitation Practices in Nigeria's Low-Income Areas

Sanitation is a fundamental human right and a cornerstone of public health, yet Nigeria continues to grapple with some of the world's most acute sanitation challenges, especially in its low-income and marginalized communities [35]. The country's sanitation landscape is shaped by a combination of rapid urbanization, poverty, weak governance, and chronic underinvestment in essential infrastructure [36]. In these contexts, basic and often unsafe sanitation systems predominate, with far-reaching consequences for environmental quality, water safety, and human health.

2.2.1 The Landscape of Sanitation: Pit Latrines, Septic Tanks, and Shared Facilities

The pit latrine is by far the most common sanitation system in low-income Nigerian communities, especially across vast swathes of the north and rural peripheries [24-27]. These latrines are typically simple, unlined holes dug into the ground, sometimes with a slab or rudimentary superstructure. Cost and ease of construction make pit latrines attractive; however, their widespread use comes at a severe environmental and health cost. Unlined pits are particularly vulnerable to collapse or flooding, and they allow fecal matter to leach into the surrounding soil posing major risks of groundwater contamination, especially during the rainy season or in areas with high water tables [3, 11].

In urban and peri-urban contexts, septic tanks and soakaway pits are more commonly found. However, construction practices are often substandard: tanks are built too close to wells, boreholes, and houses, frequently violating the WHO-recommended setback of at least 30 meters [13-17].

Many tanks are inadequately sealed or maintained, leading to seepage, overflow, and direct discharge of untreated effluent into the environment. With high population densities, frequent power outages, and irregular desludging, the risks of environmental contamination are compounded in city slums and informal neighborhoods [1-4].

Shared sanitation is another defining feature of low-income areas. In Lagos, Ibadan, and Port Harcourt, it is common for multiple households sometimes more than a dozen, to share a single toilet or pit latrine [2-3]. Overuse leads to rapid deterioration, unsanitary conditions, and loss of privacy, particularly for women and girls, who may resort to unsafe practices such as open defecation after dark [24-26]. The lack of gender-sensitive facilities and safe, dignified toilets severely limits girls' school attendance and women's participation in public life [20-22].

2.2.2 Open Defecation and Informal Practices

Open defecation remains a persistent and widespread practice in Nigeria, particularly in rural and urban poor communities. According to the 2023 Joint Monitoring Programme, over 46 million Nigerians, more than 20% of the population still defecate in the open [34]. The drivers of open defecation are multifaceted: the lack of access to affordable toilets, cultural attitudes, land scarcity, transient populations, and insufficient enforcement of sanitation bylaws all play a role [23-25].

Recent studies have highlighted the association between open defecation and outbreaks of cholera, typhoid, and other waterborne diseases, especially during the rainy season when runoff transports fecal matter into water sources [1-2]. The practice also contributes to environmental degradation, soil contamination, and the proliferation of disease vectors such as flies and rodents [25].

Efforts to eradicate open defecation have included nationwide campaigns such as the “Clean Nigeria: Use the Toilet” initiative and the scaling up of Community-Led Total Sanitation (CLTS), which empowers communities to build and maintain their own toilets [22-25]. However, these programs face challenges related to funding, monitoring, and sustainability, with many communities slipping back into open defecation after initial gains.

2.2.3 Greywater Disposal and Solid Waste Management

Sanitation challenges in low-income communities extend far beyond the management of human waste. Greywater wastewater from household bathing, laundry, and cooking is typically discharged directly into open drains, onto streets, or into water bodies, due to the near-total absence of formal sewerage or stormwater systems [28]. Pools of stagnant greywater attract mosquitoes, increase the risk of malaria and dengue, and create unsightly, foul-smelling environments that degrade quality of life and property values [29].

Solid waste management is similarly inadequate. In many slums and peri-urban neighborhoods, formal waste collection is sporadic or non-existent. Residents often resort to dumping refuse in open plots, drainage channels, or makeshift communal dumpsites [27-31]. The uncontrolled accumulation of solid waste clogs drains, exacerbates flooding, and produces leachate that seeps into groundwater and surface water sources, compounding the risks of contamination and disease [28, 29].

2.3 Hygiene Practices, Behavior, and Community Responses

Hygiene practices are a core determinant of health outcomes in any setting, but their role becomes especially pronounced in low-income areas where water and sanitation systems are weak or absent. In Nigeria, a complex interplay of social norms, behavioral patterns, infrastructure, and economic realities shapes hygiene practices and community responses, often with profound impacts on disease transmission and public health [25, 26].

2.3.1 Handwashing and Personal Hygiene

Handwashing with soap is the single most effective intervention for preventing diarrheal diseases and respiratory infections [5, 7]. In Nigeria's low-income settings, however, less than half of households report having a designated place for handwashing with both soap and water [30]. Barriers include the cost and availability of soap, unreliable water supply, and limited knowledge of hand hygiene's health benefits [23]. In a 2022 survey of peri-urban Ibadan, only 39% of respondents reported washing hands with soap after using the toilet, and only 27% before eating [13].

Menstrual hygiene management is another often-overlooked aspect. Many adolescent girls and women in low-income communities lack access to clean, private facilities and affordable sanitary products. This reinforces absenteeism from school and work, stigma, and infection risk [14, 15].

2.4 Behavioral Norms and Social Determinants

Behavioral change in hygiene practices is deeply influenced by social norms, cultural beliefs, and peer pressure. In many communities, traditional practices such as cleaning hands with sand or ash persist due to habit, misinformation, or lack of alternatives [12]. Gender roles also shape behavior; women and girls are often the primary caregivers and are responsible for managing household hygiene, but may lack the power or resources to implement best practices [12].

Socioeconomic status plays a pivotal role in shaping hygiene practices. Households with higher education levels and incomes are more likely to construct improved toilets, purchase soap, and prioritize cleanliness [1, 2, 5]. Conversely, transient populations, tenants, and informal settlers often have little control over their living environment.

2.5 Community-Led Initiatives and Social Mobilization

Community-based interventions have proved effective in catalyzing hygiene improvements. Community-Led Total Sanitation (CLTS), for example, uses participatory methods to trigger collective action, shame, and pride to end open defecation and improve hygiene [24-27]. CLTS has been piloted in numerous Nigerian states, with variable success. Some communities have achieved “Open Defecation Free” (ODF) status, but sustainability remains a challenge, especially where poverty and rapid population turnover are high. Other successful strategies include the formation of WASH committees, hygiene clubs in schools, and the use of local champions or “natural leaders” to promote behavior change [24, 35]. Faith-based organizations and traditional rulers are often trusted actors who can reinforce hygiene messages and encourage uptake.

2.6 Policy, Institutional, and Infrastructure Barriers

Water, sanitation, and hygiene (WASH) are universally recognized as fundamental human rights and are essential for achieving sustainable development and public health.

However, in Nigeria, progress toward universal access is consistently undermined by a complex web of policy, institutional, and infrastructure barriers [33-35]. These challenges are particularly acute in low-income and informal urban settlements, where the lack of coordinated policy, weak institutional frameworks, and chronic underinvestment in infrastructure have created cycles of exclusion, vulnerability, and poor health outcomes [24].

2.6.1 Policy Barriers

Fragmented Policy Frameworks

Nigeria's WASH sector is governed by a variety of national policies and strategies, including the National Water Supply and Sanitation Policy, the National Roadmap to End Open Defecation by 2025, and the National Action Plan for the Revitalization of the WASH Sector [25]. While these frameworks articulate ambitious goals, implementation has been hampered by fragmentation, overlapping mandates, and inconsistent alignment across federal, state, and local government levels [22, 35].

Multiple ministries, such as Water Resources, Environment, Health, and Urban Development share responsibility for WASH, leading to duplication of effort, policy incoherence, and a lack of accountability [30]. For example, the Federal Ministry of Water Resources is tasked with policy formulation and coordination, but state and local governments are responsible for implementation and service delivery, often without adequate capacity, technical expertise, or funding [24, 35].

Weak Regulatory Enforcement

Even where sound policies exist, regulatory enforcement is weak. Building codes and sanitation regulations, such as minimum standards for the construction and placement of toilets, septic tanks, and boreholes are rarely enforced in low-income and informal settlements [20]. The proliferation of substandard, unsafe, and environmentally hazardous sanitation facilities is a direct consequence of this regulatory vacuum, as is the widespread contamination of groundwater and surface water sources [16-17]. Corruption and political interference further undermine enforcement. In some cases, local officials accept bribes to overlook violations or are pressured to provide services to politically connected areas rather than those with the greatest need [35].

Policy Implementation Gaps

The gap between policy formulation and implementation is stark. While Nigeria has made high-level commitments to meet Sustainable Development Goal 6 (clean water and sanitation for all) and to end open defecation by 2025, actual progress has been slow and uneven [20]. Many states lack actionable plans or sufficient resources to operationalize national policies, and data on progress especially in informal settlements, are limited and unreliable [24].

Monitoring and evaluation systems are often weak or absent, making it difficult to track service coverage, functionality, or user satisfaction. As a result, many interventions are “invisible” to policymakers, and successful innovations are not scaled up [35].

2.6.2 Institutional Barriers

Decentralization and Local Government Weakness

Nigeria's federal system decentralizes substantial responsibility for WASH service delivery to state and local governments.

However, these entities often lack the capacity, resources, and technical expertise needed to plan, finance, and manage services effectively [13, 14]. Local government authorities who are closest to the communities they serve are frequently under-resourced, poorly staffed, and constrained by political interference and corruption [7-9].

In some regions, rural water supply and sanitation agencies exist only on paper, and community-based management structures have limited reach or sustainability. In urban areas, the proliferation of parallel institutions (e.g., urban water utilities, health departments, sanitation boards) creates confusion, duplication, and competition for resources [35].

Inadequate Human and Financial Resources

Chronic underinvestment in human capital is a major institutional barrier. The WASH sector suffers from a shortage of trained engineers, public health officers, social mobilizers, and regulatory inspectors, especially at the local level [34]. Training programs and career incentives are limited, and staff turnover is high, further reducing institutional memory and capacity.

Financial constraints are even more severe. Public financing for WASH is inadequate, unpredictable, and often misallocated. Most funding goes to urban water supply and visible infrastructure, while sanitation, hygiene promotion, and peri-urban or informal settlements receive little attention [35]. The lack of pro-poor financing mechanisms means that the poorest households are unable to afford improved facilities or pay for ongoing maintenance, perpetuating cycles of exclusion and disease.

Lack of Data and Evidence-Based Planning

Reliable data on WASH coverage, functionality, and quality in informal settlements are limited. Many low-income areas are not officially mapped, and service providers (public or private) rarely collect data on user needs, satisfaction, or willingness to pay [25-27]. This data deficit impedes effective planning, budgeting, and monitoring. Where data do exist, they are often outdated, inconsistent, or not disaggregated by gender, age, or vulnerability, limiting the ability to design inclusive, targeted interventions [35].

2.6.3 Infrastructure Barriers

Aging and Inadequate Infrastructure

Much of Nigeria's water and sanitation infrastructure is aging, under-designed, or poorly maintained. In major cities like Lagos and Kano, piped water networks reach only a fraction of the population, and even where pipes exist, intermittent supply, poor water quality, and frequent breakdowns are the norm [3, 4]. Informal settlements and peri-urban neighborhoods are rarely connected to municipal systems.

Sanitation infrastructure is equally deficient. Sewerage systems are virtually non-existent outside a few central business districts, and most households rely on pit latrines, septic tanks, or shared facilities, many of which are unsafe, unhygienic, or prone to flooding [5, 6]. Solid waste management is sporadic at best, with most refuse disposed of in open areas, drainage channels, or illegal dumpsites [2-4].

Informal and Unregulated Service Provision

In response to infrastructure gaps, a thriving informal sector has emerged, including private water vendors, borehole drillers, and pit latrine emptiers [5-7].

While these actors provide essential services, the lack of regulation and quality control leads to variable standards, price gouging, and environmental hazards. For example, private boreholes and wells are often drilled without regard to hydrogeological factors or safe distances from sources of contamination (Ofoegbu *et al.,* 2022). Informal pit emptying and waste disposal practices can lead to sewage being dumped in open drains or water bodies, further polluting the environment [3].

Land Tenure and Settlement Patterns

Land tenure insecurity is a pervasive barrier to infrastructure investment in informal settlements. Most residents lack legal claims to their land, deterring both household and public investment in durable water and sanitation facilities [24, 27]. Government agencies are often unwilling to extend services to informal areas for fear of legitimizing "illegal" settlements, further entrenching exclusion and vulnerability.

Settlement patterns with high density, narrow streets, unplanned layouts pose practical challenges for infrastructure extension and maintenance. Construction of new water mains, sewers, or drains is expensive and logistically complex, while the risk of eviction discourages long-term investment by residents or service providers [24, 35].

Climate Change and Environmental Hazards

Infrastructure resilience is further compromised by climate change. Increased frequency and severity of floods, droughts, and extreme weather events damage water and sanitation systems, exacerbate contamination risks, and create new challenges for urban planners and communities [1-3]. Informal settlements on floodplains and wetlands are especially vulnerable, and the lack of drainage or solid waste management increases the risk of disease outbreaks following disasters [36].

2.7 Septic Tank Systems in Low-Income Nigerian Communities

Septic tank systems are, for many Nigerians living in low-income urban and peri-urban settlements, the only available means of managing household wastewater and human waste [3]. These systems are omnipresent in the crowded neighborhoods of Lagos, Ibadan, Enugu, Kano, and dozens of other cities where rapid population growth and rural-urban migration have far outpaced the development of municipal sewerage networks [4]. In these areas, the septic tank is not just a sanitation technology, it is a reflection of deeper patterns of poverty, informality, and governance challenges that shape daily life and public health outcomes [5].

2.7.1 Typical Design and Operation of Septic Tanks

In theory, a septic tank is a straightforward engineering solution: a watertight underground chamber, designed to receive and settle household sewage, where solids sink and undergo partial breakdown by anaerobic bacteria. The remaining liquid effluent is supposed to flow into a soakaway pit or drain field, where further natural treatment occurs before the water seeps into the environment. Ideally, such a system is built from reinforced concrete or high-quality bricks, sized to accommodate the number of users, and sited at a safe distance of at least 30 meters from any drinking water source [25, 36].

However, the reality in low-income Nigerian communities diverges sharply from this ideal. Here, septic tanks are commonly constructed with whatever materials are affordable or immediately available. Unreinforced cement blocks, scrap metal, or even repurposed oil drums are often used in place of standard materials [36]. The tanks are frequently undersized, as landlords and homeowners try to minimize costs or lack the technical knowledge to calculate proper volumes. Many tanks lack essential features such as baffles or multiple chambers, which are critical for separating solids from liquids and preventing clogging of the soakaway [6].

In these crowded environments, septic tanks are sometimes built just a few meters from wells, boreholes, or streams, despite international safety recommendations. Space constraints and unplanned urban layouts mean that tanks may be constructed beneath communal courtyards, beside kitchens, or in places where children play and families gather. There is little or no technical supervision during construction, and official building regulations are rarely enforced [7].

Once in operation, these tanks function more as holding containers than as treatment systems. Wastewater from toilets, and in some cases kitchens and baths, flows directly into the tank. With inadequate design and poor sizing, solids accumulate quickly, and the tank fills much faster than intended. Liquid effluent, often still rich in pathogens and organic matter, seeps into the soil or, in worst-case scenarios, is deliberately channeled into open drains or nearby water bodies, contributing to widespread environmental contamination [8].

2.7.2 Patterns of Installation and Maintenance

The patterns of installation and maintenance for septic tanks in low-income Nigerian communities are shaped by the broader context of informality and survival. In many neighborhoods, landlords and tenants commission local artisans or masons rarely trained engineers, to construct tanks. The process is guided by necessity and improvisation rather than by technical blueprints or best practices. Tanks are often squeezed into whatever space is available, with little regard for optimal siting, accessibility, or future maintenance needs [9].

Once installed, septic tanks are largely out of sight and out of mind. Regular inspection, preventive maintenance, and scheduled desludging the hallmarks of effective septic tank management are rare. Instead, maintenance is reactive: tanks are only emptied when they overflow, emit foul odors, or cause visible pollution. In shared compounds, where dozens of people may rely on a single tank, the frequency of failure is even higher, and responsibility for maintenance is often contested or unclear [10].

Formal desludging services, using vacuum trucks, are expensive and logistically challenging. Many low-income communities are inaccessible to these trucks, either because of narrow, unpaved roads or because the cost is prohibitive for residents. As a result, informal pit emptiers operating without any regulatory oversight are frequently engaged. These workers may use crude tools to manually scoop out sludge, which is then dumped illegally into open drains, vacant plots, or even watercourses, creating a major public health hazard [11].

There is little public awareness of the long-term risks associated with poorly maintained septic tanks. Most households and landlords lack the technical knowledge to understand the importance of tank sizing, siting, and regular maintenance. Record-keeping is virtually nonexistent, and minor leaks or cracks are often ignored or patched with makeshift materials. The cumulative effect is a sanitation system that is highly prone to failure, fostering frequent overflows, environmental contamination, and the spread of disease [12].

2.8 Socioeconomic and Regulatory Factors Affecting Septic Tank Use

The patterns described above are not accidental. They are the result of deeply rooted socioeconomic and regulatory factors.

2.8.1 Poverty

Poverty is the most obvious barrier. Most households in low-income Nigerian communities cannot afford to construct septic tanks to recommended standards or to pay for regular maintenance. Landlords especially in informal settlements prioritize short-term savings over long-term safety, often building the cheapest possible tanks with the smallest possible capacity [13]. The lack of secure land tenure further discourages investment; families facing the constant threat of eviction or demolition have little incentive to build durable infrastructure [14].

2.8.2 High Population Density and Shared Living Arrangements

High population density and shared living arrangements put additional stress on already fragile systems. In compounds or "face-me-I-face-you" buildings, single tanks may serve dozens of users, filling and failing far more quickly than intended. Because tenants often move frequently, collective responsibility for maintenance is diluted, and disputes over desludging costs are common [15].

2.8.3 Weak Regulatory Oversight

Regulatory oversight is weak. Although building codes, environmental regulations, and public health laws technically require safe siting and construction of septic tanks, these standards are rarely enforced in low-income or informal settlements. Municipal authorities lack the staff, resources, or political will to monitor or enforce compliance. Corruption and informal payments can allow unsafe practices to continue unchecked [35].

The informal private sector dominates both the construction and emptying of septic tanks. Artisans and emptiers operate with no formal training, licensing, or accountability. As a result, there is wide variation in construction quality and maintenance practices, and environmental or health risks are rarely prioritized [16]. The consequences of these failures are severe. Groundwater contamination is widespread, as leaking or overflowing septic tanks pollute wells and boreholes, the primary sources of drinking water for most households. Outbreaks of waterborne diseases such as cholera, typhoid, and dysentery are tragically common, particularly during the rainy season when flooding spreads contaminants even further [2, 36].

2.9 Moving Forward: Challenges and Opportunities

The situation, though daunting, is not without hope. Pilot projects and interventions in some Nigerian cities have shown that progress is possible when local governments, NGOs, and community organizations work together. Subsidies for improved tank designs, training programs for local masons, and the introduction of affordable desludging services have had positive impacts in some urban centers [35].

Moreover, increased public awareness and community engagement are crucial. When residents are informed about the risks of poor sanitation and are empowered to demand better services, there is greater pressure on both landlords and local authorities to improve standards. Strengthening regulation, improving municipal capacity, and incentivizing safe practices in the private sector are also key steps toward safer and more sustainable sanitation. Ultimately, addressing the challenges of septic tank systems in low-income Nigerian communities requires a holistic approach, one that combines technical solutions, governance reforms, pro-poor investment, and community empowerment. Only by tackling the underlying socioeconomic and institutional barriers can safe, dignified, and sustainable sanitation become a reality for all.

Ultimately, addressing the challenges of septic tank systems in low-income Nigerian communities requires a holistic approach, one that combines technical solutions, governance reforms, pro-poor investment, and community empowerment. Only by tackling the underlying socioeconomic and institutional barriers can safe, dignified, and sustainable sanitation become a reality for all.

2.10 Mechanisms of Groundwater Contamination from Septic Tanks

The issue of groundwater contamination from septic tanks is critical in low-income Nigerian communities, where these systems are often the default method for domestic wastewater disposal. The contamination process is complex, involving the movement of both pathogens and chemicals from the septic tank into the surrounding soil and, ultimately, into aquifers that supply drinking water. This process is driven by a combination of system design flaws, inadequate maintenance, high population density, and environmental conditions [17]. In these settings, septic tanks are frequently constructed with minimal regulatory oversight, using substandard materials and without adequate consideration of site characteristics or environmental safety.

When septic tanks are not properly constructed or maintained, they can develop cracks or leaks, allowing untreated or partially treated wastewater to escape. Even when tanks are functioning as intended, the liquid effluent is typically discharged into a soakaway pit or drain field that may be inadequately sized or located too close to groundwater sources [2]. Over time, especially as tanks reach capacity or soils become saturated, contaminants can more easily bypass natural attenuation processes. The frequent absence of inspection and regular desludging further compounds the risk, as solids accumulate and systems become overloaded. During heavy rainfall or flooding, which is common in many Nigerian cities, septic systems can be inundated, causing effluent to flow directly into the environment and increasing the likelihood of rapid contaminant transport into groundwater [36].

The cumulative impact of these failures is substantial. In many urban and peri-urban areas, the contamination of groundwater by improperly managed septic tanks is a significant factor behind persistent waterborne disease outbreaks and chronic environmental degradation [18]. This problem is exacerbated by the reliance of many communities on shallow wells and boreholes for their primary water supply, creating a direct pathway for human exposure to hazardous contaminants [35].

The cumulative impact of these failures is substantial. In many urban and peri-urban areas, the contamination of groundwater by improperly managed septic tanks is a significant factor behind persistent waterborne disease outbreaks and chronic environmental degradation [19]. This problem is exacerbated by the reliance of many communities on shallow wells and boreholes for their primary water supply, creating a direct pathway for human exposure to hazardous contaminants [35].

2.10.1 Pathways of Microbial and Chemical Pollution (e.g., bacteria, nitrates, phosphates)

The septic tank is designed to provide primary treatment, removing solids and allowing for partial microbial breakdown of organic matter. However, the effluent that leaves the tank still contains a considerable load of contaminants, especially when tanks are undersized, overflowing, or constructed with inadequate materials [20].

Microbial Pathways

The most immediate and dangerous contaminants are pathogenic microorganisms. These include bacteria such as *E. coli* and *Salmonella*, viruses like norovirus and hepatitis A, and protozoa such as Giardia and Cryptosporidium. These pathogens can survive for extended periods in moist environments and are highly mobile in certain soil types [21]. When septic effluent percolates through permeable soils or enters fractured rock, pathogens may travel significant distances, contaminating wells and boreholes used for drinking water. Human exposure can result in outbreaks of diseases such as cholera, typhoid, dysentery, and viral gastroenteritis [2].

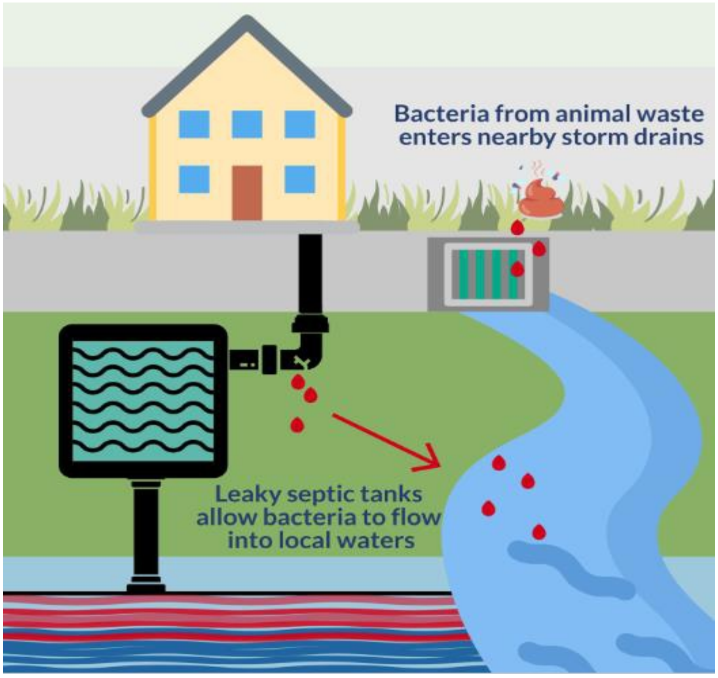

Figure 1: Microbial pollution of groundwater
Source: *Adelana & MacDonald [2]*

Chemical Pathways

Septic tank effluent also contains dissolved chemicals, most notably nitrates and phosphates. Nitrates are a product of the breakdown of urea and other nitrogenous compounds in human waste. They are highly soluble in water and do not adsorb well to soil particles, which enables them to move rapidly through the soil profile and into groundwater [22]. Elevated nitrate levels in drinking water are associated with methemoglobinemia ("blue baby syndrome") in infants and may contribute to cancer risks in adults. Phosphates, while less mobile than nitrates, can still leach into groundwater under certain soil conditions, especially if soils are saturated or have low adsorption capacity. Both nitrates and phosphates can also contribute to the eutrophication of surface waters if groundwater discharges into lakes or rivers, causing algal blooms and further degrading water quality [23].

In addition to naturally occurring compounds, household chemicals including detergents, cleaning products, and pharmaceuticals, may also be present in septic tank effluent. These substances can introduce persistent organic pollutants and heavy metals into groundwater, posing long-term risks to both human health and ecosystem integrity [24].

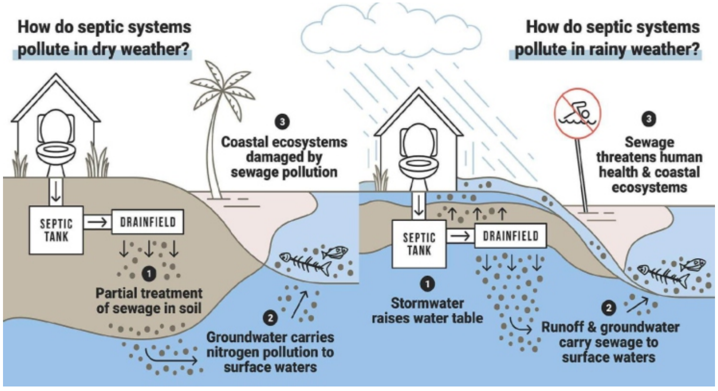

Figure 2. Chemical pollution of groundwater
Source: *Olalekan et al. [25]*

2.11 Factors Influencing Contamination Risk: Soil Type, Water Table Depth, Tank Proximity to Wells

Several site-specific and technical factors significantly influence the likelihood and severity of groundwater contamination from septic tanks in Nigerian communities.

2.11.1 Soil Type

The physical and chemical properties of the soil surrounding a septic tank are fundamental in determining the degree of natural filtration and attenuation that occurs as effluent travels toward the groundwater [24]. Sandy and gravelly soils are highly permeable and allow for rapid percolation of liquids, but they provide little filtration or microbial die-off, enabling pathogens and chemicals to reach the groundwater quickly. In contrast, clay-rich or loamy soils can slow down the movement of effluent, increasing opportunities for biological treatment and contaminant adsorption. However, excessively compacted or impermeable soils may cause effluent to surface, resulting in direct human contact and environmental contamination [25].

2.11.2 Water Table Depth

The depth of the water table the distance from the ground surface to the saturated zone, is a critical determinant of contamination risk. A shallow water table means that contaminants have less soil to traverse before reaching groundwater, reducing the effectiveness of natural attenuation processes [26]. In many Nigerian cities, the water table is particularly shallow during the rainy season, increasing the vulnerability of wells and boreholes to contamination. Conversely, a deep water table provides more opportunity for pathogens to die off and for chemicals to degrade or be adsorbed before reaching groundwater. Seasonal fluctuations in water table depth can also influence risk, with higher levels during wet periods increasing the likelihood of effluent infiltration [36].

2.11.3 Tank Proximity to Wells

The distance between a septic tank and nearby wells or boreholes is perhaps the most controllable factor in preventing contamination. International guidelines typically recommend a minimum separation of 30 meters, but this is rarely maintained in low-income or informal settlements in Nigeria, where space is limited and regulations are weakly enforced [27].

When tanks are sited too close to wells, or even directly uphill from them, contaminants have a direct pathway into the water supply. Outbreaks of waterborne diseases in such settings are often traced to this physical proximity, coupled with the absence of protective barriers such as concrete well linings or properly sealed covers [35].

2.11.4 Evidence and Case Studies from Nigeria

Septic tanks are the most common on-site sanitation system in Nigeria's rapidly expanding cities and peri-urban communities. While they serve a vital role in the absence of sewerage networks, mounting evidence from across Nigeria demonstrates that poorly constructed and maintained septic tanks are a major source of groundwater contamination. This contamination poses acute public health risks, particularly in low-income neighborhoods where monitoring and regulation are weak, water infrastructure is informal, and residents rely heavily on shallow wells for drinking water.

2.12 Review of Key Studies and Reports on Groundwater Contamination Linked to Septic Tanks

Several national and regional studies over the past decade have systematically linked septic tank use to groundwater pollution in Nigeria. The World Bank's Nigeria Water Supply, Sanitation, and Hygiene Poverty Diagnostic (2022) provides a foundational overview. This report highlights that over 60% of the Nigerian population depends on groundwater primarily accessed through hand-dug wells and boreholes for their daily water needs. In both urban and peri-urban contexts, most households use on-site sanitation, with septic tanks and pit latrines serving as the main containment systems for human waste. The diagnostic found that a majority of these systems are constructed without professional oversight, do not meet recommended design standards, and are rarely maintained or desludged, creating a direct risk of effluent seepage into surrounding soils and shallow aquifers.

Olalekan et al. [26] conducted a cross-sectional survey of water sources and sanitation practices across five Nigerian states. They found that in communities where septic tanks were located within 10 meters of wells, contamination rates measured by the presence of *E. coli* and nitrates were consistently high. The study emphasized a lack of public awareness about safe distances and the widespread use of makeshift building materials in septic tank construction.

Ofoegbu et al. [20] focused specifically on the city of Enugu, carrying out a detailed assessment of groundwater quality in relation to septic tank locations. Their findings pointed to a clear spatial correlation: wells that were closer to septic tanks, especially those situated uphill or at the same elevation, had significantly higher levels of fecal contamination and nitrate pollution. They concluded that the overwhelming majority of tanks surveyed did not meet the recommended setback distance of 30 meters from wells or boreholes.

Adelana and MacDonald [2], in a comprehensive review covering sub-Saharan Africa, identified Nigeria as a critical hotspot for septic tank-related groundwater pollution. The authors attributed this to a combination of high urban population density, widespread use of informal sanitation solutions, fragile regulatory frameworks, and a lack of investment in urban sanitation planning.

2.12.1 Examples from Major Cities and States

Lagos

As Nigeria's largest and most densely populated city, Lagos provides a stark example of the challenges posed by inadequate septic tank management. Eniola et al. [13] conducted a multi-year study in neighborhoods such as Makoko, Ajegunle, and Agege. They found that more than 80% of wells sampled tested positive for E. coli, with nitrate concentrations exceeding the World Health Organization (WHO) recommended limits in over half the samples. The researchers traced these patterns to the prevalence of septic tanks sited within just a few meters of wells, frequent tank overflows, and the city's high water table, which is seasonally exacerbated by flooding. In Makoko, a floating slum where open defecation and direct discharge of wastewater into the lagoon are also common, the contamination is acute and chronic. The Lagos State Government has reported recurrent outbreaks of cholera and other diarrheal diseases in informal settlements, frequently following periods of heavy rain when septic systems are overwhelmed, and effluent mixes with floodwaters [35].

Ibadan

In Ibadan, another major urban center, Akintola et al. [8] studied groundwater quality across multiple slum districts. The research revealed that over 60% of sampled wells contained E. coli, indicating fecal contamination, while nitrate levels above the WHO threshold were found in 44% of the wells. The study linked these results directly to the siting of septic tanks: in high-density neighborhoods, tanks were often only 5–10 meters from wells, with some tanks constructed uphill from water sources, creating a direct pathway for contaminants.

The researchers also noted that local soils are predominantly sandy, which allows effluent to travel quickly through the subsurface with minimal filtration. Communities reported frequent foul odors, visible effluent pooling on the surface, and regular disputes over tank maintenance responsibilities.

Port Harcourt

Port Harcourt, the capital of Rivers State and a major city in the oil-rich Niger Delta, faces similar but distinct challenges. The city's informal settlements, such as Diobu and Mile 1, have experienced substantial groundwater pollution due to unregulated septic tank construction and maintenance. Local health authorities and academic studies have documented frequent contamination of shallow wells, especially during the rainy season. Residents commonly report the presence of foul-tasting or discolored well water, as well as increased rates of waterborne illness after major rainfall events [35].

Northern Nigeria

In northern cities like Kano and Sokoto, groundwater contamination from septic tanks is an emerging but increasingly serious problem. Yakubu and Musa [36] documented a trend of rising nitrate levels in shallow wells in urban Kano, correlating closely with increased installation of on-site sanitation systems in rapidly expanding informal neighborhoods. The combination of a variable water table, permeable soils, and minimal regulation exacerbates the risk, as does the growing population's reliance on poorly protected wells.

2.13 Implications for Public Health and Environmental Sustainability

2.13.1 Infectious Disease Burden

A central and immediate consequence of groundwater contamination from septic tanks is the escalation of infectious diseases in affected Nigerian communities. When effluent from leaking or overflowing tanks seeps into shallow wells and boreholes, it carries with it a dangerous mix of pathogens *E. coli*, Vibrio cholerae, Salmonella, and Shigella, among them. These organisms are responsible for acute gastrointestinal illnesses, including cholera, typhoid fever, dysentery, and diarrhea [4].

Every rainy season, when tanks are most likely to overflow and the water table rises, outbreaks become common. In densely populated neighborhoods of Lagos, Ibadan, and Port Harcourt, clinics and hospitals report spikes in patients suffering from severe diarrhea and dehydration. The ubiquity of contaminated water sources means that even basic daily activities fetching water, washing, or food preparation, can serve as routes of exposure [28].

Children bear the brunt of this burden. With still-developing immune systems and higher exposure due to play and bathing, children under five are especially vulnerable. Chronic diarrheal disease in this group is a leading cause of malnutrition, developmental delays, and mortality. For mothers and caregivers, repeated bouts of childhood illness create emotional, economic, and physical strain, making it harder to break cycles of poverty [6].

2.13.2 The Threat of Antimicrobial Resistance (AMR)

Increasingly, antimicrobial resistance (AMR) is emerging as a hidden but critical threat linked to septic tank contamination. Antibiotics taken for both human and animal health reasons are excreted unchanged or as active metabolites [6]. When these drugs and resistant bacteria enter septic tanks, they create conditions conducive to the exchange of resistance genes between microorganisms. As effluent moves into groundwater, these resistant bacteria can enter the drinking water supply.

This process quietly amplifies the risk that routine infections will no longer respond to standard treatments, threatening to roll back decades of medical progress. In communities where waterborne illness is already prevalent, the emergence of hard-to-treat infections compounds the crisis, leading to longer illnesses, higher healthcare costs, and increased risk of complications or death [4].

2.13.3 Child Health and Intergenerational Impacts

The well-documented risks to child health are especially grave. Children exposed to contaminated water not only suffer more frequent and severe episodes of diarrhea but also face long-term developmental consequences. Recurrent gastrointestinal infections, particularly in the first five years of life, are linked to impaired nutrient absorption, stunted physical growth, and cognitive delays [8]. These setbacks affect educational outcomes and economic opportunities well into adulthood, perpetuating intergenerational cycles of disadvantage.

Household surveys in Nigerian slums consistently find that children living near poorly maintained septic tanks have higher rates of undernutrition and lower school attendance evidence of how environmental health hazards translate directly into lost human potential [8].

2.14 Strategies for Mitigating Groundwater Contamination

2.14.1 Improving Septic Tank Design, Siting, and Maintenance

One of the most immediate interventions to reduce the risk of groundwater contamination in Nigeria is raising the standard for how septic tanks are designed, sited, and maintained [27]. Across many Nigerian cities and peri-urban communities, septic tanks are often built with inadequate or substandard materials, sometimes even as simple unlined pits. Such practices are insufficient to contain effluent, especially in areas with high population density and shallow groundwater [28].

Design Improvements

Modern septic tanks should be constructed with watertight reinforced concrete or high-quality bricks, featuring internal baffles and multiple chambers. These features encourage solid-liquid separation and allow for partial treatment of waste before any effluent is released. Proper sizing is also essential a tank should be large enough to accommodate several years' worth of sludge accumulation, minimizing the risk of overflow [29].

Optimal Siting

The placement of septic tanks is critical. International guidelines recommend a minimum distance of 30 meters between septic tanks and any well or borehole. Tanks should be sited downhill from water sources and outside of areas prone to flooding. However, in Nigeria's crowded informal settlements, these standards are rarely met, and many tanks are found within 10 meters of household wells dramatically increasing contamination risks [35]. Before installation, basic hydrogeological surveys should be conducted to ensure that the soil is neither too permeable nor too impermeable for safe operation [30].

Regular Maintenance

Routine desludging every 2–3 years is vital, as accumulated solids can clog the system and force untreated sewage into the environment. Awareness campaigns are needed to educate householders and landlords about the importance of regular maintenance, the dangers of informal pit emptying, and options for safe desludging services [31]. Extension services and microfinance can help communities afford these upgrades.

2.14.2 Alternatives to Septic Tanks

Recognizing that conventional septic tanks may not be suitable for all settings, especially in areas with space limitations, high water tables, or porous soils, alternative sanitation technologies are gaining attention.

Decentralized Wastewater Treatment Systems (DEWATS)

DEWATS offer scalable, low-tech solutions that treat wastewater for small clusters of homes, schools, or markets. They typically include anaerobic baffled reactors, constructed wetlands, and biogas digesters. These systems have demonstrated success in Nigerian pilots by providing effective treatment, generating reusable water for irrigation, and reducing the burden on groundwater [1, 35].

Ecological Sanitation (EcoSan)

EcoSan toilets, such as urine-diverting dry toilets and composting toilets, separate liquid and solid waste at the source. This not only prevents effluent from reaching groundwater but also transforms waste into compost or fertilizer, which can then be safely used in agriculture [32].

These systems are particularly suitable for water-scarce or flood-prone communities.

Composting and Dry Toilets

In remote or arid areas, dry and composting toilets eliminate the risk of groundwater contamination by keeping waste above ground for treatment and eventual safe reuse [35]. Scaling up these alternatives requires community engagement, technical support, and market development for parts and maintenance.

2.15 Recommendations

Effectively addressing groundwater contamination from septic tanks in Nigeria demands more than just technical fixes it calls for a sustained, collaborative, and people-centered approach. The path forward starts with strong leadership and vision from government. Policy makers at every level must recognize that safe sanitation is not simply a matter of infrastructure, but a public good essential to the health, dignity, and prosperity of all citizens [32]. This means moving beyond outdated codes and sporadic enforcement, toward a responsive, well-resourced regulatory environment that insists on watertight, durable septic tanks, properly sited and routinely maintained. Such regulations must be not only written but enforced, with local authorities empowered and equipped to inspect, certify, and guide construction and operation [33, 35].

However, expecting communities especially those living in poverty to shoulder the costs of upgrading or replacing unsafe tanks is neither fair nor realistic. Here, the case for public investment and targeted financial support is clear. By offering subsidies, grants, or microloans, governments can help families and landlords afford safer systems. Investment in public desludging services, such as equipping more vacuum trucks and training operators, would ensure that even the most crowded and hard-to-reach neighborhoods are not left behind. Financial resources should also be directed toward piloting and scaling up decentralized wastewater treatment systems, especially in rapidly growing urban and peri-urban areas where conventional septic tanks are not practical [2].

But infrastructure alone cannot solve the problem. In places where traditional septic tanks simply cannot function safely due to high water tables, dense populations, or space constraints innovative alternatives must be embraced. Decentralized treatment systems, EcoSan, and composting toilets offer not just technical solutions, but new ways for communities to take ownership of their waste and protect their water. The adoption of these systems should go hand-in-hand with local supply chain development, ongoing technical support, and community-driven management, ensuring that solutions are both sustainable and locally appropriate [34].

Change on this scale depends on the hearts and minds of ordinary people. Widespread educational campaigns are needed to challenge myths, break taboos, and build trust in new technologies and practices. Community leaders, women's groups, and youth organizations must be at the forefront, not just as recipients of information, but as agents of change helping to set up local sanitation committees, monitor maintenance, and mediate disputes. When communities are involved in decision-making and ownership, interventions are more likely to last and deliver real improvements [35, 36].

At the same time, progress must be tracked and measured. Robust monitoring systems combining water quality surveillance with health data can provide early warnings of contamination, help to direct resources where they are needed most, and hold all stakeholders accountable for results. Digital tools, from mobile apps for reporting breakdowns to GIS mapping of high-risk areas, can democratize data and make it actionable [35].

Above all, this is not a task for the government alone. It calls for genuine partnership across sectors. NGOs, with their deep roots in communities, can pilot new approaches, mobilize citizens, and ensure that the voices of the marginalized are heard. The private sector can offer affordable products, innovative services, and flexible financing. Research institutions bring evidence, fresh ideas, and local adaptation. International partners can provide funding, technical expertise, and opportunities for learning from successful models elsewhere [2].

Finally, investing in local capacity training artisans, health officers, engineers, and young people will ensure that progress is not just achieved, but sustained. When communities have the knowledge and skills to build, maintain, and monitor safe sanitation systems, they are better equipped to protect their own health and environment for generations to come.

2.16 Conclusion

The challenge of groundwater contamination from septic tanks in Nigeria is both urgent and complex, touching on public health, environmental integrity, social equity, and urban development. As rapid urbanization continues and climate pressures mount, the risks posed by inadequate sanitation infrastructure are likely to intensify, manifesting in recurrent outbreaks of waterborne diseases, the spread of antimicrobial resistance, and the gradual but profound degradation of vital water resources.

Yet, the pathways to solutions are clear and achievable. By prioritizing regulatory reform, public investment, and the scaling of innovative technologies, Nigeria can make significant strides toward safe, resilient, and inclusive sanitation for all. Effective strategies must be interdisciplinary and participatory, engaging government, civil society, the private sector, and local communities as equal partners. Learning from successful interventions both within Nigeria and abroad and adapting them for local realities can accelerate progress.

Crucially, the fight to protect Nigeria's groundwater is a matter of social justice. It is the most vulnerable children, the elderly, and the urban poor who suffer first and most from contaminated water. Ensuring that every Nigerian has access to safe sanitation and clean water is not merely a technical goal but a fundamental human right and a prerequisite for national development.

By acting decisively, Nigeria can safeguard public health, restore ecosystems, strengthen social cohesion, and advance its progress toward the Sustainable Development Goals. The time for concerted action is now, with the tools, knowledge, and partnerships already within reach.

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Conflict of Interest

The authors declared that there are no conflicts of interest.

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