International Journal of Academic and Applied Research (IJAAR)
ISSN: 2643-9603
Vol. 10 Issue 8 August - 2026, Pages: 201-207

Microbial Assessment of Household Drinking-Water Sources and Their Implications for Community Health: A Critical Review of Evidence from Nigeria

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Abstract: *Household drinking water in much of Nigeria arrives without ever passing through a regulated distribution network, and this single structural fact shapes almost everything reviewed in this paper. Drawing on peer-reviewed microbiological surveys conducted mainly in Ibadan and complemented by studies from Ghana and multi-country sub-Saharan African datasets, this review examines what culture-based and molecular evidence tells us about the bacteriological safety of wells, boreholes, and packaged sachet and bottled water. The evidence is neither uniformly bleak nor reassuring. Hand-dug wells consistently show the highest contamination burden, with total coliform counts occasionally exceeding 100,000 CFU per 100 mL and Escherichia coli recovered in roughly a quarter to two-thirds of tested household sources depending on location and season. Packaged water presents a more divided picture: some Ibadan-based assessments report full microbiological compliance among sachet and bottled brands, while a national mini-review finds that four in ten sachet brands fail the WHO coliform threshold, a discrepancy that appears tied to distribution-chain hygiene rather than production standards alone. Genomic work on Ibadan well-water isolates further shows that contamination is not a static health hazard but an active reservoir for transmissible antimicrobial resistance genes, which complicates any purely water-quality framing of the problem. The paper argues that policy responses anchored solely on the WHO/UNICEF Joint Monitoring Programme's improved-versus-unimproved source classification obscure this reality, since improved sources are repeatedly shown to harbour E. coli at rates similar to unimproved ones. Community health implications, methodological limits of indicator-organism testing, and the uneven regulatory oversight of Nigeria's packaged water sector are discussed critically rather than descriptively.*

Keywords: household water microbiology; Escherichia coli indicator; Nigeria drinking water; antimicrobial resistance in water; WHO/UNICEF JMP

Introduction

The claim that access to an "improved" water source equates to safe drinking water has been repeated so often in development literature that it has acquired the texture of common sense. It is also, on the evidence reviewed here, not reliably true. In Nigeria, where the great majority of urban and peri-urban households depend on self-supplied wells, boreholes, or commercially packaged sachet water rather than piped municipal systems, the gap between infrastructural classification and actual microbiological safety has become one of the more persistent and under-addressed public health problems in the country's water sector.

This is not a new observation, but it has taken on sharper empirical form over the past several years as microbiology departments in Nigerian universities, most visibly at the University of Ibadan, have produced a run of studies that combine conventional culture-based indicator testing with molecular characterisation. Rabiu et al. (2022) sampled household wells and boreholes across the Ibadan metropolis and recovered Escherichia coli strains carrying genuine pathogenic markers, not merely the generic indicator organism the literature often treats as interchangeable with "contamination" in the abstract. A larger follow-up study spanning five local government areas in Ibadan and 447 samples collected across both dry and wet seasons found that not a single household in the study used municipal tap water, and that E. coli was recovered from just over a quarter of all water sources tested (Alabi et al., 2024). These are not obscure findings buried in grey literature; they were published in peer-reviewed outlets and they describe a city of roughly three million people.

The problem, however, is not confined to untreated well water, and this is where the picture becomes genuinely more complicated rather than simply worse. Nigeria's packaged water sector, dominated by sachet ("pure water") sales and a smaller bottled water market, was supposed to function as a private-sector correction to the state's failure to deliver piped water. The evidence on whether it has succeeded is mixed to the point of contradiction. One assessment of 25 sachet and bottled brands sold within Ibadan found no microbiological contaminants at all (Airaodion, 2019), while a national-scope mini-review synthesising data from 2005 onward concluded that 40 percent of sachet brands tested exceeded the WHO coliform threshold of ten organisms per 100 mL (Ogundare &

Isah, 2020). Both findings cannot be generalised into a single verdict on "sachet water" as a category, and treating them as if they could is one of the analytical weaknesses this review tries to avoid.

This paper synthesises that body of evidence critically rather than descriptively. It asks three interlinked questions. First, what do indicator-organism data from Nigerian household water sources actually tell us, and what do they fail to tell us, about the risk to consumers. Second, how should the divergence between well-water and packaged-water findings, and the divergence within packaged-water findings themselves, be interpreted analytically rather than simply reported as inconsistency. Third, what are the implications of recent molecular evidence showing that contaminated household water functions as a reservoir for antimicrobial resistance, a dimension almost entirely absent from the older water-quality literature and one that changes the policy stakes considerably.

Well and Borehole Water: A Consistent but Uneven Burden

The most heavily documented Nigerian case is Ibadan, partly an artefact of research infrastructure (the University of Ibadan's microbiology department has produced a sustained programme of work here) and partly because the city's water situation is genuinely severe. Alabi et al. (2024) is the most methodologically ambitious of the recent studies: 447 samples across five municipal LGAs, disaggregated by dry season (n=250) and wet season (n=197), tested for pH, total aerobic counts, coliform counts, and screened by both phenotypic and multiplex PCR methods for E. coli, Salmonella, Shigella, and Yersinia. Wells accounted for 53.2 percent of household sources and boreholes for 34 percent; no household drew on municipal supply at all. Aerobic and coliform counts, along with pH, varied significantly between seasons, though the direction of change was not uniform across LGAs, which the authors treat as evidence that local hydrogeology and sanitation infrastructure matter as much as rainfall itself. E. coli was isolated from 115 of 447 sources (25.7 percent), and thirty-three Salmonella isolates were also recovered, though no Shigella or Yersinia.

Earlier work cited within that same Ibadan literature reports considerably higher contamination in hand-dug wells specifically. Odeleye and Idowu's survey of wells and boreholes across five LGAs found 96 percent of hand-dug wells contaminated, with total and fecal coliform counts reaching as high as 160,000 and 22,000 CFU per 100 mL respectively, an order of magnitude that makes the more recent 25.7 percent E. coli figure look almost conservative by comparison (Alabi et al., 2024). Ayantobo et al. , sampling 101 wells across four LGAs, reported somewhat lower but still concerning figures, with coliform counts up to 685 CFU per 100 mL, and noted that many of the wells sampled were physically unprotected, lacking the concrete apron or covered headworks that basic well-protection guidance requires (Alabi et al., 2024). Combined together, these three Ibadan studies, spanning different sampling periods and slightly different LGA coverage, are not perfectly comparable, but the direction of the evidence is unambiguous: wells in this city are chronically and substantially contaminated, and the degree of contamination reported has if anything fluctuated rather than declined over the period these studies cover.

It would be a mistake, though, to read this as a Nigeria-specific pathology. A multi-country analysis of 4,499 rural households across nine sub-Saharan African countries found that 69 percent had access to what the WHO/UNICEF Joint Monitoring Programme classifies as an "improved" water source, yet E. coli was detected in 67 percent of those improved-source households (cited study, PMC, 2024). That figure is the single most analytically important number in this literature, because it directly undermines the assumption, still embedded in a great deal of national and donor water policy, that infrastructural improvement is a reasonable proxy for microbiological safety. An improved source in this dataset was roughly as likely to test positive for E. coli as not. The same study's use of elimination regression, a technique for narrowing down predictor variables across a large candidate set, is methodologically worth noting because it moves the literature away from simple prevalence reporting toward an attempt at explaining variation, though the authors themselves are candid that clustering and sample weighting were not fully accounted for, a limitation that matters when generalising the results to other regions.

Sachet water occupies an unusual position in Nigerian public health discourse. It emerged largely as an informal, low-capital response to unreliable municipal supply, and by the 2010s had become the dominant mode of drinking water access in many urban areas, particularly among lower-income households who cannot afford sunk costs like borehole drilling. The regulatory apparatus meant to police it, principally NAFDAC (the National Agency for Food and Drug Administration and Control), registers and periodically inspects producers, but the enforcement record described in the literature is patchy rather than absent.

The empirical picture is genuinely inconsistent across studies, and this inconsistency deserves more analytical attention than it usually receives. Airaodion (2019) assessment of 25 sachet and bottled brands sold in Ibadan between late 2018 and early 2019 found the samples "free from microbiological contaminants" and fully compliant on heavy metals as well. A separate national-scope mini-review, synthesising peer-reviewed studies published from 2005 onward, reached a considerably less reassuring conclusion: 40 percent of the fifteen sachet brands it evaluated failed the WHO coliform standard of ten organisms per 100 mL, while all bottled water samples in the same synthesis met potability standards (Sustainable Water Resources Management mini-review, 2020). A

third, more localised study around the Madala-Zuba axis found the opposite asymmetry: sachet water samples were microbiologically clean, while two of ten bottled water brands tested positive for organisms including Enterobacter aerogenes and Shigella species (Shehu 2025).

These are not simply contradictory findings that cancel each other out. They plausibly reflect a sector where product quality is determined less by the water source or production method, and more by handling conditions between the factory gate and the point of sale, a distinction the literature on contamination pathways supports. Work reviewed by researchers examining Nigerian sachet water attribute a substantial share of contamination, in the range of 40 to 45 percent by one older estimate, to conditions occurring between distribution centres and street vendors rather than during production itself (Omalu 2010). If that attribution is correct, and it is broadly consistent with findings from Ghana's comparable sachet water market where similar hygiene gaps have been documented, then the divergent results across Nigerian studies may simply reflect which point in the supply chain each study happened to sample from, and how long the tested batch had been sitting in ambient heat before analysis. This is a more useful explanation than treating one study as "right" and another as "wrong," though it is also, admittedly, an inference rather than something these studies directly test against each other.

An older but still relevant study from Western Nigeria examined 92 sachet-packaged water samples across several towns and found total bacterial counts ranging from 2.86 to 3.45 log CFU per mL, with E. coli detected in only 2.2 percent of samples, a rate considerably lower than most well-water figures cited above (Olaoye & Onilude, 2009). The authors attributed the contamination they did find to poor personal and environmental hygiene among handlers rather than to raw water sourcing, a conclusion that anticipates the distribution-chain explanation offered above by more than a decade.

Emerging Concern: Water as an Antimicrobial Resistance Reservoir

The most consequential recent addition to this literature does not concern contamination prevalence at all, but what happens to the organisms once they are present Rabiu et al. took 25 E. coli isolates recovered from thirteen Ibadan household wells in the earlier Rabiu et al. (2022) study and subjected them to antibiotic susceptibility testing and whole-genome sequencing (Rabiu et al., 2025). Fifteen of the twenty-five isolates displayed a multidrug-resistant phenotype, and eighteen carried identifiable resistance genes conferring resistance to trimethoprim-sulfamethoxazole, macrolides, and sulphonamide-class drugs among others. Critically, the study went further than simple prevalence reporting by testing whether resistance was transmissible: using a conjugation protocol with a nalidixic-acid-resistant recipient strain, the researchers demonstrated that plasmid-borne resistance genes could move horizontally between bacterial strains, meaning that contaminated well water is not merely a source of infection but an active site where resistance genes circulate and spread between organisms, independent of any single infection event.

This finding reframes what a "contaminated well" actually represents. Under the older indicator-organism paradigm, a well testing positive for E. coli is treated primarily as a fecal contamination signal, a proxy for the probability that a consumer might ingest an enteric pathogen. Under the newer genomic framing, the same well is also a genetic exchange environment, and the antibiotics that Nigerian households routinely use, often without prescription (a practice documented separately in the antibiotic utilisation literature the same research group cites), may be actively selecting for resistant strains that then persist and circulate in the domestic water supply. This is a considerably more difficult problem to address through conventional water treatment interventions like chlorination or boiling, which reduce bacterial load but do not eliminate a resistance gene pool already established in a household's water storage and distribution practices.

Data Sources

The evidence base draws on peer-reviewed journal articles published primarily between 2019 and 2025, supplemented by a small number of earlier foundational studies (notably Olaoye and Onilude's 2009 sachet water study) where they remain the most direct available source for a specific claim and where later literature explicitly builds on or cites them. Sources include studies published in the Journal of Water and Health, PLOS One, Sustainable Water Resources Management, and institutional reports from the WHO/UNICEF Joint Monitoring Programme. Priority was given to studies conducted in Nigeria, with comparative material drawn from Ghana and a nine-country sub-Saharan African dataset used to test whether Nigeria-specific patterns reflect a broader regional dynamic or a more localised one.

Analytical Approach

The paper uses a thematic synthesis approach, coding the reviewed literature against three organising themes identified inductively during the review process: (1) contamination prevalence and severity by water source type, (2) methodological approach and its bearing on comparability across studies, and (3) the policy and public health implications scholars themselves draw from their findings, including any implicit or explicit critique of existing regulatory frameworks. Rather than presenting each study sequentially,

findings are grouped and cross-examined by theme, allowing points of convergence and, more importantly, unresolved contradiction (as with the sachet water findings) to be surfaced and interrogated directly rather than smoothed over.

Scope and Limitations

Three limitations bear directly on how the findings below should be read. First, the literature is geographically concentrated: Ibadan-based research dominates the Nigerian evidence base disproportionately relative to the size and diversity of the country's water access contexts, meaning findings from northern Nigeria's semi-arid zones or the Niger Delta's distinct hydrogeology and pollution profile are comparatively underrepresented in what is reviewed here. Second, cross-study comparability is imperfect: sampling seasons, laboratory protocols (membrane filtration versus most-probable-number methods, for instance), and reporting units differ across the studies synthesised, which limits the precision of any direct numerical comparison even where general patterns are consistent. Third, this review does not itself generate new microbiological data, and its conclusions are therefore bounded by the quality and completeness of the primary studies it draws on; where a primary study's own limitations (such as the unweighted clustering noted in the nine-country regression analysis) affect the reliability of a finding, that caveat is carried forward rather than treated as resolved.

Findings

Table 1 summarises the principal studies reviewed, organised by water source type and location.

Study / Location	Water Source(s)	Sample Size	Key Microbial Finding	Reference
Municipal Ibadan (5 LGAs)	Hand-dug wells, boreholes	447 (dry n=250, wet n=197)	E. coli in 25.7% of sources; no household used municipal tap water; 86.8% nonpotable in dry season	Alabi et al. (2024)
Peri-urban Ibadan (Akinyele, Lagelu)	Household wells	13 households, 25 E. coli isolates	High coliform/E. coli counts; recovered isolates showed transmissible multidrug resistance	Rabiu et al. (2022); Rabiu et al. (2025)
Ibadan hand-dug wells (historical)	Hand-dug wells	Wells across five LGAs	96% highly contaminated; TC/FC up to 160×10^3 and 22×10^3 CFU/100 mL respectively	Odeleye & Idowu, cited in Alabi et al. (2024)
Ibadan (4 LGAs)	Hand-dug wells	101 wells	Coliform up to 685 CFU/100 mL; E. coli up to 74 CFU/100 mL; many unprotected	Ayantobo et al., cited in Alabi et al. (2024)
Nine countries, rural sub-Saharan Africa	Mixed improved/unimproved	4,499 households	69% used improved sources; E. coli still detected in 67% of those households	Fejfar et al. cited study (2024, PMC)
Western Nigeria (multi-town)	Sachet-packaged water	92 samples	Total bacterial count 2.86–3.45 log CFU/mL; E. coli in 2.2% of samples	Olaoye & Onilude (2009, ScienceDirect)
Nigeria (national mini-review)	Sachet and bottled water	15 sachet brands	40% of sachet brands exceeded WHO coliform limit; all bottled samples potable	Mini-review, Sustainable Water Resources Management (2020), cited in Ogundare et al.

Three patterns emerge from this body of evidence with sufficient consistency to be treated as findings rather than isolated observations.

First, contamination severity correlates more strongly with source protection status than with source type in the abstract. Hand-dug wells, particularly unprotected ones lacking a sealed headworks or apron, consistently register the highest and most variable contamination levels, with total coliform counts spanning several orders of magnitude across studies (from under 100 to over 100,000 CFU per 100 mL). Boreholes, which are typically drilled deeper and sealed, do not appear as a distinct low-risk category in the Ibadan data; the 2024 study by Alabi et al. does not report separately favourable results for boreholes relative to wells, suggesting that construction quality and maintenance, rather than nominal source type, are doing the analytical work.

Second, packaged water quality is not a stable category and should not be treated as one in policy communication. The range of findings, from full compliance in one Ibadan assessment to a 40 percent sachet failure rate in a national synthesis, is wide enough that a single public health message ("sachet water is safe" or "sachet water is unsafe") would misrepresent the evidence regardless of which direction it took. The more defensible reading is that packaged water safety is contingent on point-of-sale handling and storage duration in ways that vary by vendor and location, a hypothesis consistent with the distribution-chain contamination estimates noted earlier but one that would require supply-chain-specific sampling to confirm rigorously.

Third, and least discussed in Nigerian public health communication, contamination in household water is increasingly documented as a vector for antimicrobial resistance rather than solely a fecal-oral disease risk. The Rabiu et al. (2025) finding that resistance genes are transmissible between isolates recovered from the same water sources implies that the health burden of contaminated wells is not fully captured by counting diarrhoeal disease cases; it may also include a slower, less visible contribution to the region's antimicrobial resistance burden, a link that current Nigerian water policy does not appear to address explicitly.

Table 2 sets out the interpretive limits of the principal indicator organisms used across this literature, which bear directly on how the findings above should be weighted.

Indicator	What It Signals	Interpretive Caveat
Total coliforms	General sanitary quality; presence of a broad bacterial family found in soil, vegetation and gut environments	Poor specificity for fecal origin; regrowth in biofilm-laden storage containers can inflate counts without a fresh contamination event
Fecal coliforms / thermotolerant coliforms	Higher likelihood of recent fecal input	Still includes some environmental organisms; not a substitute for pathogen-specific testing
Escherichia coli	Considered the most reliable routine indicator of recent fecal contamination	Presence does not establish which pathogens, if any, accompany it; most environmental E. coli strains are non-pathogenic, and virulence typing is rarely performed outside research settings
Heterotrophic plate count	Overall bacterial load and treatment/storage hygiene	Weak correlation with health outcomes on its own; more useful as a trend indicator across seasons than a pass/fail threshold
Salmonella, Shigella (direct isolation)	Confirms presence of specific enteric pathogens	Low recovery rates even where indicator counts are high, partly reflecting intermittent shedding and culture sensitivity limits

Discussion

The central analytical tension this review surfaces is between infrastructural and microbiological definitions of water safety, and Nigeria's household water situation is, in effect, a live test case of what happens when the two definitions diverge sharply. The JMP's improved-source framework, for all its value in tracking coverage trends globally, was not designed to capture the specific failure mode documented in Ibadan: a city where boreholes and wells, both nominally improved sources under most national classification systems, are contaminated at rates that would place them below even the JMP's "basic" threshold if microbiological testing were actually incorporated into the classification. The absence of piped municipal water in the entire 447-household Ibadan sample, a detail easy to skim past, means that essentially the whole sampled population is relying on self-supplied sources that fall outside the kind of centralised quality monitoring that safely managed status is meant to imply exists.

This raises an uncomfortable methodological point for national water statistics more broadly. If Nigeria's own reported JMP coverage figures classify boreholes and protected wells as improved sources without routine testing, then national safe-water-access statistics may be systematically overstating actual microbiological safety, not through data fabrication but through a definitional gap built into the monitoring architecture itself. This is not a uniquely Nigerian problem; the nine-country sub-Saharan African regression study demonstrates the same gap operating at a regional scale. But the severity documented in Ibadan, a major urban centre with functioning universities, hospitals, and a comparatively strong research infrastructure, suggests the gap is not simply a rural or remote-area artefact that better infrastructure investment alone would resolve.

The packaged water evidence complicates any simple policy prescription further. If the divergence in sachet water findings genuinely reflects distribution-chain hygiene rather than production-site failures, then interventions focused on NAFDAC's factory-level inspection regime, which is where regulatory attention has historically concentrated, may be addressing the wrong point in the supply chain. A vendor storing sachets in direct sunlight for extended periods, or handling them with unwashed hands at a roadside stall, introduces a contamination risk that no amount of factory-level quality control can prevent. This is speculative rather than firmly

established by the studies reviewed here, since none of them explicitly track the same batch of water from factory to point of sale, but it is a more parsimonious explanation for the contradictory findings than assuming one set of researchers simply made methodological errors that another set avoided.

The antimicrobial resistance dimension deserves particular emphasis because it has been almost entirely absent from Nigerian water policy discourse, which remains framed predominantly around diarrhoeal disease reduction and, more recently, cholera outbreak response. The Rabiu et al. (2025) findings suggest a second-order consequence of poor water quality that operates on a longer timescale and through a different causal pathway: not through acute infection, but through the accumulation and horizontal transfer of resistance genes in a population's water environment, genes that can later surface in clinically relevant infections regardless of whether those infections are themselves waterborne. If this pattern holds beyond the 25 isolates examined in that specific study, and there is no principled reason to think Ibadan's wells are uniquely conducive to this process compared to similarly contaminated wells elsewhere in the country, then Nigeria's antimicrobial resistance strategy and its water and sanitation policy are arguably addressing two faces of the same underlying problem without currently being coordinated to do so.

There are limits to how far this argument can be pushed on the available evidence. The resistance-transmission study drew on a small, geographically concentrated isolate set, and generalising its implications nationally would outrun what 25 isolates from 13 households can support. Similarly, the packaged water contradictions discussed above remain, on the current evidence, a plausible interpretation rather than a demonstrated mechanism; a supply-chain-tracking study specifically designed to test the distribution-hygiene hypothesis has not, to this reviewer's knowledge, yet been conducted in the Nigerian context, and until it is, competing explanations, including production-batch variability or differences in analytical protocol between research teams, cannot be fully ruled out.

What the evidence does support, with reasonable confidence, is a policy recommendation that is more specific than the generic calls for "improved water infrastructure" that dominate much of the grey literature on this topic. Nigerian water quality monitoring would benefit from incorporating routine, source-type-agnostic microbiological testing into its classification system rather than relying on infrastructural proxies alone, and Nigeria's antimicrobial resistance surveillance strategy would benefit from including household water testing as a monitored environmental reservoir rather than treating clinical isolates and environmental samples as separate surveillance streams. Neither recommendation requires new technology; both require redirecting existing laboratory capacity, much of which is already demonstrated by the very studies reviewed here, toward a more integrated monitoring design.

Conclusion

The evidence reviewed here does not support a single, tidy verdict on the safety of household drinking water in Nigeria, and that resistance to simplification is itself among the more important findings of this synthesis. Wells, and hand-dug wells especially, are contaminated at levels that should concern any public health authority, with E. coli recovery rates and coliform counts that vary by study but rarely fall to levels consistent with safe drinking water guidelines. Packaged water occupies a genuinely contested empirical space, where the same product category yields both fully compliant and substantially non-compliant results depending on which study, location, and point in the supply chain is examined, a pattern that points toward distribution and handling failures rather than a uniform verdict on sachet water as an industry. And running beneath both of these findings is a newer and less publicly visible concern: that contaminated household water functions not only as a route for acute gastrointestinal illness but as an active site for the circulation and transfer of antimicrobial resistance genes, a dimension that current Nigerian water and health policy has not yet meaningfully absorbed into its planning.

The broader implication for water and sanitation policy in Nigeria, and by extension for comparable contexts across sub-Saharan Africa where the same infrastructural-versus-microbiological gap has been documented, is that coverage statistics built on the JMP's improved-source ladder should be read as a floor for policy ambition rather than a ceiling for public health confidence. Achieving universal basic water access, itself still a distant target for much of the region, would not on the evidence reviewed here resolve the microbiological safety problem, since a substantial share of the contamination documented occurs within sources that already count as improved. Closing that gap will require testing regimes, regulatory enforcement along distribution chains rather than only at production sites, and a water-health policy architecture that treats antimicrobial resistance surveillance and drinking water quality as connected rather than parallel concerns.

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