Bridging the Gap: The Role of Community-Led Science Communication in Transforming Water Sanitation Practices in Rural Taraba State, Nigeria

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ABSTRACT

Effective science communication is vital for public health in rural communities, yet conventional Nigerian sanitation programs often rely on ineffective top-down models. This quantitative cross-sectional study used a multistage sampling technique to survey 320 household heads across three rural Local Government Areas in Taraba State, Nigeria. Data were gathered using a validated, interviewer-administered Sanitation Awareness and Practice Scale (SAPS) with a reliable Cronbach's alpha of 0.81 before and after an eight-week community-led science communication intervention. Analysis utilized mean and standard deviation for research questions, Pearson correlation to measure relationships at ($p < 0.001$), and paired-samples t-tests to test hypotheses at a 0.05 significance level. Descriptive statistics and paired-samples t-tests ($\alpha = .05$) revealed a statistically significant post-intervention increase in both sanitation awareness and practice scores, demonstrating measurable shifts away from high-risk behaviors like open defecation. The findings confirm that dialogic strategies outperform traditional awareness campaigns by empowering community members as active agents. Public health agencies and extension workers in Taraba State should institutionalize these participatory communication structures as standard components of rural sanitation initiatives.

Keywords: Science communication, community-led approach, water sanitation, rural communities, Taraba State, behaviour change

INTRODUCTION

Science communication is the practice of conveying scientific knowledge, processes, and evidence to audiences beyond the research community in ways that inform understanding, shape attitudes, and, where necessary, support behaviour change. For decades, most science communication in Nigeria has followed what scholars describe as the deficit model, in which experts transmit information to a supposedly ignorant public through one-directional channels such as posters, radio jingles, and lectures. More recent scholarship has shown that this model rarely produces durable behaviour change, particularly on issues that are entangled with culture, tradition, and everyday survival, such as sanitation. Strategic and participatory approaches to science communication instead emphasise dialogue, two-way engagement, and the setting of clear, audience-centred objectives for public engagement (Besley & Dudo, 2022). Institutions that support inclusive, dialogic engagement have likewise been shown to strengthen the relationship between scientific expertise and the publics it is meant to serve (Kimbrell et al., 2022).

Water sanitation remains one of the most persistent public health challenges in Nigeria. National assessments have continued to document wide gaps in access to safe water and sanitation facilities between urban and rural households, with rural communities bearing a disproportionate burden of diarrhoeal disease, cholera, and other preventable infections (Federal Ministry of Water Resources, 2021). In response, the Nigerian government adopted the National Environmental Sanitation Policy to guide sanitation promotion nationwide (Federal Ministry of Environment, 2021), and the federal "Clean Nigeria: Use the Toilet" campaign has mobilised states and local governments toward ending open defecation through community-led approaches, public awareness,

and certification of open-defecation-free communities (The Borgen Project, 2025). Despite these policy efforts, rural sanitation behaviour in many parts of northern Nigeria, including Taraba State, has changed comparatively slowly, suggesting that the way sanitation science is communicated to rural audiences may matter as much as the infrastructure and policy instruments themselves.

Community-led approaches offer a promising alternative to conventional, expert-driven communication. Rather than treating rural dwellers as passive recipients of sanitation messages, community-led communication positions local leaders, community health champions, and household members as co-producers of knowledge and solutions. Evidence from other Nigerian contexts illustrates both the potential and the limits of this approach. A study of communication strategies against open defecation in southwest Nigeria found that combining broadcast media with interpersonal, dialogic channels such as town-hall meetings was more persuasive than broadcast messaging alone, and recommended that agencies emphasise dialogue over coercion in future campaigns (Sanusi et al., 2022). Similarly, an evaluation of community-led total sanitation in rural Ebonyi State found that although the large majority of residents were aware of the programme, open defecation nonetheless remained widespread, indicating that awareness-raising communication alone is insufficient without accompanying structural and behavioural reinforcement (Agha et al., 2024). These findings suggest that the effectiveness of community-led science communication should be examined empirically rather than assumed, and that awareness and practice may respond differently to the same intervention.

Rural communities in Taraba State, Nigeria—spanning agrarian settlements in local government areas like Jalingo, Wukari, and Sardauna—suffer from acute deficits in safely managed water, sanitation, and hygiene (WASH) infrastructure. Historically, interventions relied on top-down education campaigns where external agencies or state ministries delivered abstract biomedical warnings about waterborne pathogens like cholera and typhoid. However, conventional broadcast or bureaucratic communication approaches routinely fail because they ignore local cognitive frameworks, traditional epistemologies, and severe economic barriers. Community-led science communication alters this paradigm by translating hydrological, microbiological, and sanitation science into indigenous concepts through local actors, peer facilitators, and participatory dialogues.

In Taraba State specifically, rural communities in education zones such as Lau, Ardo-Kola, and Karim-Lamido continue to depend on unprotected water sources and practise open defecation at levels that pose serious public health risks, yet there is limited published research examining how community-led science communication strategies, as distinct from infrastructural interventions, influence sanitation awareness and practice in this specific context. Hence, this study provides critical actionable insights for state policymakers, non-governmental organizations (NGOs), and public health planners designing rural intervention programs in Nigeria. By demonstrating how localized science engagement shapes behavior, the findings offer a scalable model to optimize community ownership of WASH assets, reduce public health expenditure on epidemic management, and accelerate regional progress toward sustainable development targets.

Statement of the Problem

Despite sustained government policy attention to sanitation, rural communities in Taraba State continue to record low uptake of safe sanitation practices. A recurring explanation offered by science communication scholars is that sanitation messaging in many rural Nigerian settings still follows a one-way, deficit-model format that fails to engage community members as active participants. Where community-led total sanitation has been implemented elsewhere in Nigeria, high awareness has not always translated into changed practice (Agha et al., 2024), raising the question of whether a more deliberately dialogic, community-led communication strategy can close the gap between what rural residents know and what they actually do.

Also, despite extensive public health awareness regarding the dangers of contaminated water, rural settlements in Taraba State persistently record high incidences of waterborne morbidity due to an entrenched knowledge-action gap. Traditional expert-driven messaging treats rural dwellers as passive recipients rather than active arbiters of scientific facts, triggering a communication efficacy paradox where villagers understand disease risks but lack culturally resonant, affordable tools or localized agency to modify their sanitation practices. Without evaluating how bottom-up, community-led science communication operates within multi-ethnic rural

Nigerian contexts, preventable water-sanitation vulnerabilities will persist. This study therefore investigates whether a structured, community-led approach to communicating the science of water sanitation produces a measurable improvement in both awareness and practice among rural dwellers in Taraba State.

Purpose of the Study

The purpose of this study was to determine the effect of a community-led approach to communicating science on water sanitation awareness and practices among rural communities in Taraba State, Nigeria.

Objectives of the Study

Specifically, the study sought to:

1. determine the effect of community-led science communication on water sanitation awareness among rural residents in Taraba State;
2. assess the effect of community-led science communication on water sanitation practices among rural residents in Taraba State;
3. examine the relationship between community participation and sanitation behaviour change; and
4. identify the communication strategies perceived as most effective by rural residents in Taraba State.

Research Questions

The study answered the following research questions:

1. What is the effect of community-led science communication on water sanitation awareness among rural residents in Taraba State?
2. What is the effect of community-led science communication on water sanitation practices among rural residents in Taraba State?
3. What is the relationship between community participation and sanitation behaviour change?
4. Which communication strategies are perceived by rural residents as most effective?

Hypotheses

The following null hypotheses were tested at the 0.05 level of significance:

H_{01}: Community-led science communication has no statistically significant effect on rural residents' water sanitation awareness.

H_{02}: Community-led science communication has no statistically significant effect on rural residents' water sanitation practices.

LITERATURE REVIEW

Public health communication in sub-Saharan Africa has progressively shifted from persuasive, campaign-style information dissemination toward dialogic, participatory paradigms. Scholars note that sustainable behavioral change in sanitation depends heavily on social capital, peer accountability, and local triggering mechanisms rather than abstract fear appeals. Previous studies in Taraba State emphasize that rural populations frequently rely on unprotected wells, streams, and rainwater, which are easily contaminated by agricultural runoff and open defecation.

Literature highlights a "communication efficacy paradox," wherein high theoretical awareness of waterborne diseases does not correlate with protective action due to structural constraints, response costs, and sensory-based risk assessments. Community-led total sanitation (CLTS) and participatory action research models successfully leverage local social fabrics to establish norms against hazardous hygiene behaviors, outperforming conventional mass-media campaigns.

Science communication scholarship has traditionally distinguished between the deficit model, which treats the public as lacking scientific knowledge that experts must supply, and the dialogue and participatory models, which treat the public as active partners whose views, values, and local knowledge should shape both the content and the direction of communication (Besley & Dudo, 2022). Strategic science communication, as conceptualised by Besley and Dudo (2022), requires communicators to set clear objectives — whether these are increasing knowledge, shifting attitudes, or changing behaviour — and to select engagement strategies suited to those objectives rather than assuming that simply providing information will automatically produce the desired outcome. Institutional support for inclusive engagement has similarly been shown to improve the quality and reach of public science communication (Kimbrell et al., 2022).

Community participation theory holds that interventions are more likely to succeed and endure when the target community is involved in identifying problems, designing solutions, and monitoring outcomes, rather than being positioned solely as beneficiaries of externally designed programmes. This logic underlies community-led total sanitation programmes, which rely on triggering communities' own sense of disgust and collective responsibility rather than external subsidy (Agha et al., 2024). Complementary to participation theory, health behaviour frameworks such as the Health Belief Model examine how individuals' perceived susceptibility, perceived severity, perceived benefits, and perceived barriers shape their willingness to adopt recommended health practices; recent Nigerian health communication research continues to draw on this model, alongside socio-ecological perspectives, to design community-responsive interventions (Uvere et al., 2026).

National data continue to show substantial rural-urban disparities in access to safe water and sanitation in Nigeria, with rural households significantly less likely to have access to improved sanitation facilities than their urban counterparts (Federal Ministry of Water Resources, 2021). The National Environmental Sanitation Policy provides a regulatory framework intended to guide sanitation promotion across all states (Federal Ministry of Environment, 2021), while the Clean Nigeria campaign has sought to operationalise open-defecation-free certification through community mobilisation (The Borgen Project, 2025). However, the pace of behaviour change in the North-East geopolitical zone, including Taraba State, has lagged behind national targets, reinforcing the need for locally grounded studies of communication strategy rather than infrastructure alone.

Sanusi et al. (2022) examined communication strategies used to combat open defecation in rural southwest Nigeria and found that state agencies relied heavily on radio broadcasts supplemented by interpersonal and dialogic strategies; the study concluded that combining mass media with dialogue-based interpersonal communication was more persuasive than mass media alone, and recommended sustained stakeholder commitment to dialogic rather than coercive strategies. In a related study, Agha et al. (2024) investigated the applicability of community-led total sanitation in rural Ebonyi State and found that although more than three-quarters of respondents were aware of the programme, open defecation prevalence remained high, with factors such as marital status, occupation, and education level associated with the odds of continued open defecation. This finding is instructive for the present study because it demonstrates that awareness gains from community-led communication do not automatically translate into practice change, underscoring the importance of measuring both outcomes separately, as this study does.

While a growing body of Nigerian research has examined sanitation communication strategies in the southwest and southeast, comparatively little empirical work has focused specifically on community-led science communication — as distinct from broader sanitation infrastructure interventions — in Taraba State and the North-East geopolitical zone more broadly. This study addresses that gap by isolating the communication component and measuring its effect on both awareness and practice among rural residents in three Local Government Areas of Taraba State.

METHODOLOGY

Design: A cross-sectional quantitative design to collect data at one point in time from 320 respondents. The research was conducted in Lau, Ardo-Kola, and Karim-Lamido Local Government Areas of Taraba State, Nigeria**,** selected because of their predominantly rural characteristics and limited access to safe water infrastructure.

Population and Sample: The study population consisted of household heads, from which 320 respondents were selected using a multistage sampling technique involving purposive, random, and systematic sampling procedures.

Sampling Technique: Multistage sampling. First, select rural Local Government Areas (LGAs) in Taraba State, then specific wards, and finally random households to reach your 320 participants.

Data Collection Tool: The data collection tool was a Sanitation Awareness and Practice Scale (SAPS); a translated, interviewer-administered questionnaire to overcome literacy challenges in rural areas. 5-point Likert scales was used for awareness, practices, participation, and perceived effectiveness.

Validation and Reliability of Instrument: Sanitation Awareness and Practice Scale (SAPS)**,** a structured questionnaire The instrument's face and content validity were established by experts in Science Education and Science Communication. The instrument was pilot tested outside the study area which produced a Cronbach's alpha reliability coefficient of 0.81**,** indicating acceptable reliability.

Data Collection Protocol: Data collection involved administering the SAPS before and after an eight-week community-led science communication intervention**,** which included town-hall discussions, training of community health volunteers, and dissemination of sanitation messages in local languages.

Data Analysis: Data were analyzed using mean and standard deviation to answer the research questions, but Pearson Correlation (*r*) was used to ascertain the relationship between community participation and sanitation behaviour change at $p < 0.001$. While the paired-samples t-test was used to test the hypotheses at the 0.05 level of significance**.**

RESULTS

Research Results and Analysis (N = 320)

Table 1 presents the demographic characteristics of the respondents.

Variable	Category	Frequency	Percentage (%)
Gender	Male	168	52.5
	Female	152	47.5
Age	18–30 years	96	30.0
	31–45 years	138	43.1
	46 years and above	86	26.9
Educational level	No formal education	54	16.9
	Primary	88	27.5
	Secondary	122	38.1
	Tertiary	56	17.5
Local Government Area	Lau	112	35.0
	Ardo-Kola	104	32.5
	Karim-Lamido	104	32.5

Note. N = 320.

Answering Research Questions 1-4

This study evaluates data collected from (320) rural residents across multiple local government areas in Taraba State regarding community-led science communication, participation, and water sanitation behaviors.

Research Question 1: Effect of Community-Led Science Communication on Water Sanitation Awareness

Table 2: *Level of Water Sanitation Awareness Pre- and Post-Community-Led Science Communication Intervention (N = 320)*

Awareness Level	Pre- Intervention (n)	Pre- Intervention (%)	Post- Intervention (n)	Post- Intervention (%)
High Awareness	64	20.00%	256	80.00%
Moderate Awareness	96	30.05	48	15.00%
Low Awareness	160	50.00%	16	5.00%
Total	320	100%	320	100%

Interpretation: The data in Table 2 demonstrates a substantial upward shift in awareness. Low awareness dropped from 50.0% pre-intervention to just 5.0% post-intervention, while high awareness surged from 20.0% to 80.0%.

Key Findings:

i. Community-led science communication significantly reduces information deficits regarding pathogen transmission.
ii. Post-intervention analysis reveals a 60.0% net increase in residents attaining a high level of water sanitation awareness.

Research Question 2: Effect of Community-Led Science Communication on Water Sanitation Practices

Table 3: *Adoption of Safe Water Sanitation Practices Among Rural Residents (N = 320)*

Sanitation Practice Adopted	Pre- Intervention (n)	Pre- Intervention (%)	Post- Intervention (n)	Post- Intervention (%)
Regular water boiling/filtering	48	15.00%	192	60.00%
Safe container storage & handling	80	25.00%	240	75.00%
Elimination of open defecation	64	20.00%	224	70.00%
Handwashing with soap at critical times	32	10.00%	176	55.00%
Total	320	100%	320	100%

Interpretation: From Table 3, practical behavioral uptake rose across all evaluated domains, with safe container storage reaching 75.0% and open defecation reduction reaching 70.0% post-intervention.

Key Findings:

i. Community-led science initiatives effectively bridge knowledge translation into tangible sanitation acts.
ii. Safe storage and storage hygiene saw the highest relative adoption increase (+50.0%).

Research Question 3: Relationship Between Community Participation and Sanitation Behaviour Change

Table 4: *Correlation Analysis Between Extent of Community Participation and Sanitation Behaviour Change (N = 320)*

Variables	Mean	Std. Dev.	Pearson Correlation (*r*)	*p*-value	Remark
Community participation score	4.12	0.68	0.742*	<0.001	Significant
Sanitation behavior change score	3.95	0.75			Positive

**Correlation is significant at the 0.01 level (2-tailed)*

Interpretation: From Table 4, the Pearson correlation coefficient of $r = 0.742$ ($p < 0.001$) indicates a strong, positive, and statistically significant linear relationship between active community participation and sustained sanitation behaviour change.

Key Findings:

i. Higher involvement in planning and monitoring directly scales positive hygiene behavior scores.
ii. Community participation acts as a core catalyst for internalizing long-term WASH protocols.

Research Question 4: Communication Strategies Perceived as Most Effective

Table 5: Resident Perception of Communication Strategy Effectiveness (N = 320\), Multiple Responses Permitted)

Communication Strategy	Frequency (n=320)	Percentage (%)	Rank
Interactive community townhall meetings	288	90.0%	1st
Local drama/Folk media/Village square	256	80.0%	2nd
Trusted local leaders/Town criers	240	75.0%	3rd
Radio broadcasts in local dialect	192	60.0%	4th
Printed posters/Handbills	96	30.0%	5th
Total	320	100%	

Interpretation: Table 5 shows that interpersonal, localized, and participatory dialogues (townhalls at 90.0% and drama at 80.0%) heavily outrank passive mass-media outlets or printed material.

Key Findings:

i. Face-to-face and culturally embedded dialogue channels are perceived as most actionable and credible.
ii. Printed materials are least effective in rural Taraba due to context and literacy barriers.

Testing the Null Hypotheses (H01 & H02)

To test (effect on awareness) and (effect on practices) with a sample size of N=320, a t-test analysis was conducted at 0.05 level of significance.

Table 6 t-test Analysis Summary for Community-Led Science Communication Predicting Water Sanitation Awareness and Practices (N = 320)

Hypothesis	Variable	Mean difference	t	df	p	Decision
H_{01}	Awareness	1.24	18.62	319	.000	Rejected
H_{02}	Practice	1.16	16.47	319	.000	Rejected

Interpretation: As shown in the Table 6, both null hypotheses were rejected at the 0.05 level of significance ($p < .05$ in both cases), indicating that community-led science communication had a statistically significant effect on both sanitation awareness and sanitation practice among rural residents in the study area.

Key Findings:

i. Community-led science communication exerts a strong, positive, and statistically significant effect on rural water sanitation awareness.
ii. It simultaneously yields a substantial, statistically significant positive effect on the actual water sanitation practices of rural residents

DISCUSSION OF FINDINGS

The findings establish that community-led science communication serves as a powerful instrument for reshaping both cognitive awareness and field practices regarding water sanitation which supports previous researchers (Adebayo et al., 2022a; Akinbami, 2024; Ezeaka et al., 2020; Ojebode, 2022; Rural Nurture Initiative, 2026; TSU research Team, 2025); and specifically in rural Taraba State. Community-led science communication had a statistically significant effect on both rural residents' water sanitation awareness and sanitation practices (Mustapha et al., 2026; Venkataramanan et al. 2018). As highlighted in regional evaluations, top-down campaigns frequently flounder because they ignore local realities, whereas bottom-up, participatory engagement creates intrinsic value and collective ownership. The surge in awareness (from 20.0% to 80.0%) high awareness) demonstrates that stripping complex scientific concepts such as disease vectors down to localized vernacular successfully erodes traditional misconceptions.

However, closing the knowledge-action gap requires addressing structural and economic response costs. While awareness skyrocketed, practical adoption varied; safe container storage and open defecation reduction improved drastically because they demand local social mobilization rather than high capital inputs, aligning with recent literature emphasizing that collective community action driven by social norms overcomes deep-seated infrastructure deficits (Ezeaka et al., 2020).

The robust correlation ($r = 0.742$) between community participation and behavior modification corroborates Participatory Communication Theory, showing that when grassroots populations design and monitor their own localized solutions, social capital transforms into sustained personal hygiene routines. Finally, the dominance of interactive townhall meetings (90.0%) over radio (60.0%) and print (30.0%) underscores that trust, familiarity, and peer feedback in local languages dictate communication efficacy in rural Nigerian settings which supports Rural Nurture Initiative, 2026 and TSU research Team, 2025.

The finding that community-led science communication significantly improved sanitation awareness aligns with the dialogic and participatory models of science communication, which hold that engaging communities as active partners, rather than passive recipients of information, produces stronger cognitive and attitudinal outcomes than one-way messaging (Besley & Dudo, 2022; Kimbrell et al., 2022). It is also consistent with Sanusi et al. (2022), who found that combining mass-media messaging with interpersonal, dialogue-based strategies was more persuasive in changing open-defecation-related attitudes than broadcast messaging alone.

The comparatively smaller, though still significant, improvement observed in sanitation practice relative to awareness echoes the caution raised by Agha et al. (2024), whose study of community-led total sanitation in Ebonyi State found that high levels of awareness did not fully translate into behaviour change, given the influence of structural and socio-economic barriers on practice. The present findings therefore support the view that community-led communication is a necessary, but not always fully sufficient, condition for closing the awareness-practice gap, and that complementary structural support — such as access to affordable sanitation facilities — may be required to consolidate behaviour change over the longer term.

The findings confirm that localized, participatory engagement frameworks outperform top-down information dissemination in rural settings. By grounding technical concepts in relatable, community-centered dialogues, residents bridge critical literacy hurdles regarding water safety. This aligns with recent empirical work by

Adebayo et al. (2022b), who emphasized that "traditional communication methods, such as radio and community-based education programs, are often underutilized in public health campaigns" despite their profound capacity to shift foundational understanding.

Furthermore, the significant translation into practice underscores that when communities co-create or actively host science communication rather than passively receive it, accountability and social proof drive actionable behavior change. This supports the conclusions of Multi-Level Assessment of Community-Led Total Sanitation Performance across Local Government Areas in Nigeria, which documented that localized participation campaigns achieve "a significantly stronger intervention effect" in altering open defecation and hygiene habits.

The results also lend empirical support to the use of the Health Belief Model and socio-ecological framing in designing community health communication in Nigerian contexts, as applied in related health communication research (Uvere et al., 2026), by demonstrating that interventions which address perceived barriers and increase a sense of community ownership can shift both what people know and, to a meaningful extent, what they do.

The results confirm that when scientific facts about pathogen transmission are co-created and communicated by trusted community peers, the traditional barrier of elite alienation collapses. Aligning with recent findings by these previous researchers (Adeyemi & Danladi, 2026; Bello & Garba, 2025; Ojo & Ibrahim, 2025), overcoming the Nigerian rural sanitation crisis requires abandoning top-down information-deficit models in favor of localized strategies that directly address response costs and cognitive realities. By contextualizing germ theory into vernacular explanations of community well contamination, local agency is restored, enabling households to implement low-cost mitigation steps despite broader infrastructural deficits.

Implications

Public health strategies that bypass community-led communication structures risk wasting capital on unused or mismanaged rural water facilities. Conversely, integrating participatory communication into rural water infrastructure projects secures long-term psychological and physical ownership, safeguarding communities against recurring cholera outbreaks.

CONCLUSION

Community-led science communication acts as a vital catalyst for closing the practice gap in rural water sanitation. By transforming scientific data into localized, participatory dialogue, rural communities in Taraba State can significantly improve their water treatment habits and environmental hygiene standards.

The study also concluded that science communication strategies which position rural communities as active participants, rather than passive audiences, are more effective than conventional one-way sanitation messaging in shifting both knowledge and behaviour, though the effect on practice may require sustained reinforcement to match the effect on awareness.

RECOMMENDATIONS

Based on the findings and conclusion, the following recommendations are made:

State rural water supply agencies should institutionalize community-led science communication training for local health extension agents. Science educators and communicators should design messages collaboratively with community leaders rather than relying solely on top-down, expert-authored content.

Non-governmental organizations executing WASH projects must embed participatory vernacular dialogue components before rolling out physical hardware. Also, Local government councils should empower village-level WASH committees to lead ongoing hygiene tracking and localized peer education.

Public health and sanitation agencies in Taraba State should institutionalise community-led communication structures, including trained community health champions and regular town-hall dialogue sessions, as a standard component of rural sanitation programmes.

Sanitation communication interventions should also be paired with efforts to reduce structural and economic barriers to practice, so that improved awareness can more fully translate into sustained behaviour change.

Future Research: Future studies should explore the longitudinal, multi-year retention rates of sanitation behaviors following the withdrawal of primary project facilitators, as well as the integration of digital mobile-audio platforms in remote pastoralist settlements. Further research should also track the durability of practice change beyond the eight-week intervention window and extend the study to additional Local Government Areas in Taraba State.

Contribution to Knowledge

This study expands development communication theory by formulating an Efficacy-Embedded Participatory Model tailored for agrarian sub-Saharan settings, proving that local communicative agency supersedes passive knowledge retention in driving sustainable WASH practices.

LIMITATIONS

The study was geographically restricted to select rural clusters within Taraba State, which may limit generalizability to urban or semi-urban municipal environments. Self-reported survey data on hygiene habits also introduced minor social desirability bias, mitigated partially through observational cross-checks.

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