Journal of Engineering Geology and Environmental Research
Volume 2 (1), 2026. pp 1 - 15

ISSN: 2992-5657

Hydro-Physicochemical Quality and Microbial Safety of Water Used by Food Vendors in Oke-Owa, Ogun, Southwestern Nigeria: Implications for WASH, Hydrological Vulnerability, and Public Health

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Abstract

Inadequate hygiene and unsafe water in informal food-vending areas present serious public-health hazards particularly in the fast-urbanizing areas of Nigeria. In this paper, the hydro-physicochemical quality, microbial contamination and hygienic determinants of the water sources used by 100 food vendors were evaluated in Oke-Owa Community, Ijebu-Ode, Ogun State. The samples of water collected at five widespread sources of vendors were evaluated in terms of pH, TDS, alkalinity, hardness, ORP, ions, and heavy metals by using the standard guidelines of American Public Health Association. E. coli, Salmonella spp, and total count of coliform was measured using microbiological tests. The findings indicated that the water was very acidic (pH 4.00 – 4.50), low TDS (21.5 – 30 ppm), zero alkalinity, low traces of hardness, and high ORP (159 – 232 mV) meaning that it had high oxidizing capacity and low buffering capacity. Contamination with microorganisms was extreme: E. coli was detected in 74 percent of samples, Salmonella spp. in 68 percent and the average TCC of $8.36 \pm 2.03 \times 10^5$ CFU/mL. Logistic regression revealed that training of vendors and access to clean water were significantly associated with compliance to hygiene. The result of Principal Component Analysis revealed three behavioral domains that include personal hygiene, cross-contamination control, and environmental sanitation. Results point to hydrological instability, inadequate water governance, and water sanitation and hygiene (WASH) deficits that all increase health vulnerabilities. The adoption of the World Health Organization Water Safety Plan strategies is vital in protecting the health of the people in informal markets.

Keywords: Water Quality; WASH; Hydrology; Food Vendors; Microbial Contamination.

Introduction

Safe drinking water is still a significant issue of public-health concern in low- and middle-income countries, where hydrogeological susceptibility, urbanization, and poor sanitation are the factors of spreading waterborne diseases. The World Health Organization (WHO, 2023a) estimates that 1.7 billion people in the world drink faecally contaminated water, with the informal food-vending setting being the most impacted due to the low quality of water and the lack of hygiene

(Food and Agriculture Organization (FAO /WHO, 2021). The street food industry in Nigeria is important in terms of nutrition and employment but is undermined by the lack of safe water supply, poor sanitation, and low hygiene that predisposes the industry to food-borne outbreaks (Omemu & Aderoju, 2008; Oranusi & Braide, 2012). Water quality is also affected by seasonal flooding, shallow wells, and closeness to latrines (Adetunde *et al*., 2020).

Water safety is determined by hydrological processes like infiltration, runoff, leaching, and ground water recharge (Morris *et al*., 2003). Fecal contamination is higher during the rainy season because the wastes are washed down into wells and drainage systems (Figure 1) (Oyebog *et al*., 2021; Park, 2023; Olukayode *et al*., 2025). Low mineralization, acidic groundwater, weak buffering power may increase pathogen survival and dissolution of heavy-metals (Edet and Nganje, 2014). Hydrological risks and poor hygiene are combined with the Water, Sanitation and Hygiene (WASH) factors, such as the type of sanitation, water storage, and the hygiene of the vendors, which allows cross-contamination, despite the fact that water could be originally safe (Barro *et al*., 2006; Ahaneku and Adeoye, 2014).

Vendor water that contains pathogens like E. coli, Salmonella spp., Shigella, and Total Coliform Count (TCC) can cause gastrointestinal diseases due to contamination of food by pathogens during handwashing, rinsing, and food preparation (Mensah *et al*., 2002, Olukayode *et al*., 2025). Nigeria is associated with contaminated water utilized by the vendors who cause diarrhoea, typhoid fever, dysentery and cholera outbreaks (Adebayo-Tayo *et al*., 2012; Alimi, 2016). A combined study of hydrological variables, microbial loading, and hygiene behaviours would contribute to the evidence-based information or data in informal markets policy making. Nevertheless, there are still major gaps in research. To begin with, the literature of integrated studies that concomitantly assess the physicochemical quality of water, microbial contamination and the behaviors of vendors in the informal markets is lacking. Second, the use of multivariate and inferential statistical methods is limited, which limits a deeper understanding of interplay between environmental, microbial, and behavioural factors affecting water contamination. Third, informal food vending systems in developing countries like Nigeria have inadequate localized, data-based evidence to guide policymaking and targeted interventions to address the issue.

This paper fills these gaps by evaluating physicochemical water quality, microbial risks, hygiene determinants, and statistical modelling based on Chi-Square, Principal Component Analysis (PCA), analysis of variance (ANOVA) and logistic regression with interpretation of results in accordance with WHO Water Safety Plan (WSP) phases. The research aims are to assess the hydro-physicochemical quality and microbial safety, behavioral predictors, and to compare the results with WHO-WSP so that the results can be improved at the market level with regard to the public-health (Table 1).

The study was done in Oke-Owa Community in Oke-Aje Market at Ijebu-Ode, Ogun State (Figure 2). This congested business center relies on ground water and water points controlled by vendors. The unconfined Basement Complex aquifer is a very shallow type that is very susceptible to microbial intrusion (Adeyemi *et al*., 2021). Rainfall (1,500–2,000 mm) is seasonal and causes drain and latrine recharge, runoff, and contaminant transportation (Olawuyi & Dada, 2022). Lack of drainage and close proximity of pit latrines to the wells increase the risk of contamination as it conforms to the high-risk informal-market category as defined by WHO (WHO, 2023a).

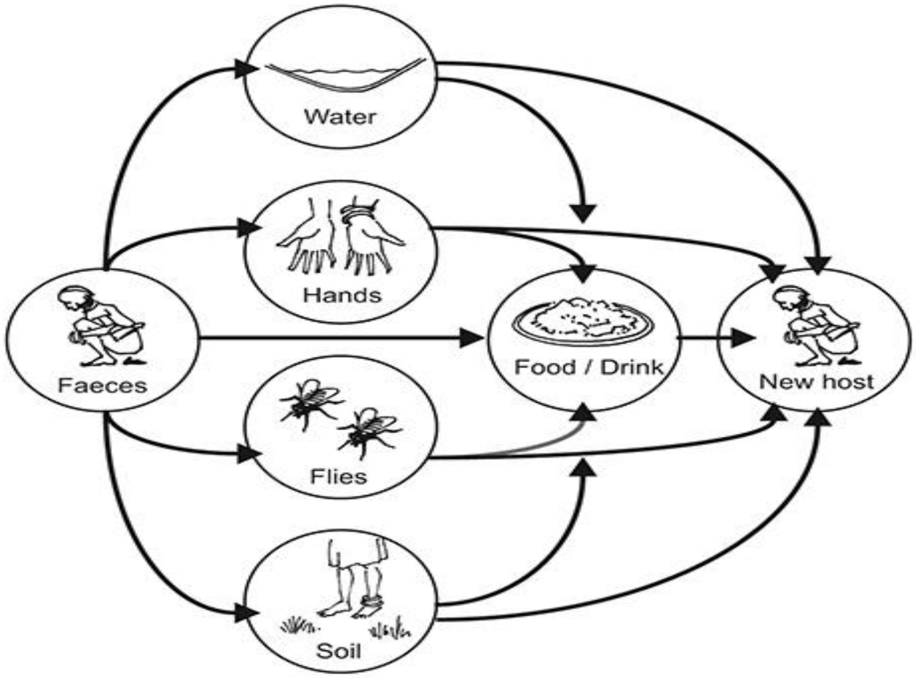

Figure 1: Fecal-Oral Route F-Diagram (Park, 2023)

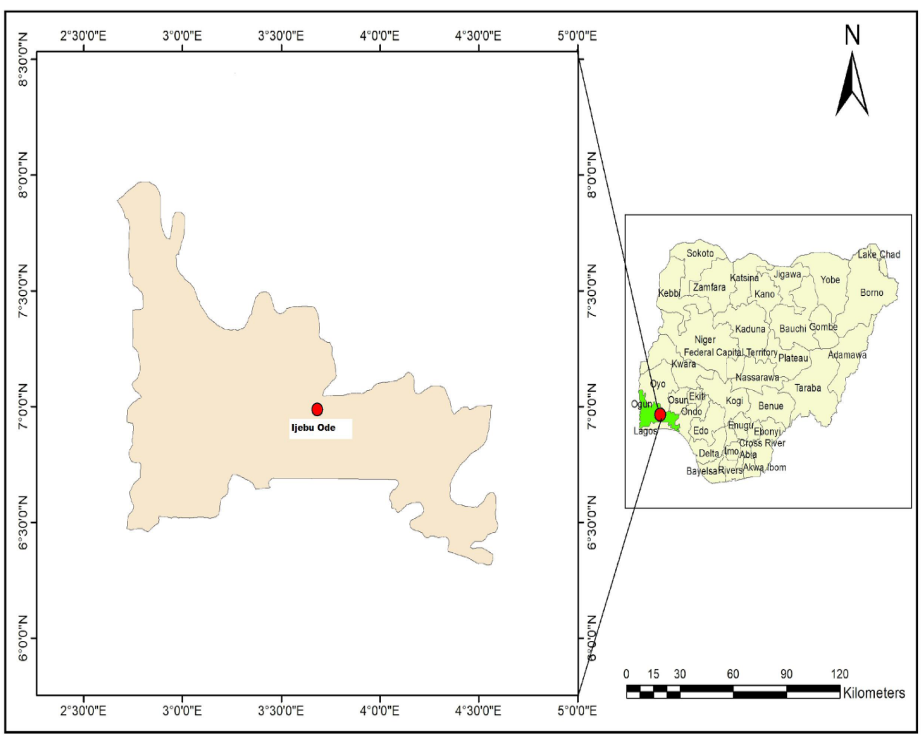

Figure 2: Study Area Map of Ogun State showing the study area (Inset: Map of Nigeria)

Materials and Methods

An analytical design of cross-section was used to evaluate the physicochemical and microbiological quality of water that food vendors use, as well as associated hygiene behaviours. This design is popular in WASH and environmental monitoring research since it allows contaminating profiling over a particular time (Rahman *et al*., 2021; WHO, 2022). Laboratory analysis, structured surveys, and statistical modeling were combined in order to produce a multidimensional interpretation of hydrological risks and determinants of hygiene behaviour.

The participants of the study were 100 food vendors that were sampled in the Oke-Aje Market, Ijebu-Ode, Ogun State, by means of stratified random sampling, to represent the key categories of vending activities, following the methods employed in Nigerian studies on food-safety (Okareh *et al*., 2022). These five important sources of water (coded sample A to E, your reader must see, at this point, at least these sources on a very legible map or table, with the coordinates and description) were selected on the basis of their frequency of use, preference by vendors, and the ease at which they could be contaminated, in accordance with WHO and the United Nations Children Emergency Fund, UNICEF (2021) advice on the selection Sterilized 1 L bottles, aseptic methods, and temperature-controlled transportation were used to collect water samples with the WHO (2022), American Public Health Association (APHA, 2017; 2022), and FAO/WHO (2021) water sampling procedures to ensure microbial integrity.

Physicochemical analyses were based on APHA techniques (2017; 2022), and in situ measurements of temperature and calibrated meters of pH, TDS, and Oxidation reduction potential (ORP) parameters were suitable to evaluate the survival of microorganisms and disinfectant conditions (WHO, 2023b). The determination of alkalinity and hardness was conducted using titrimetric techniques (APHA 2320B; 2340C) and the determination of the anions was done with the help of colorimetric and ion-selective methods. Atomic absorption spectroscopy (AAS) was used to analyze the heavy metals (Pb , Fe , and Hg) according to the Environmental Protection Agency (EPA) and the APHA standards, which gives valuable information on aquifer geochemistry and possible toxicological risks (Ayeni and Oladunjoye, 2023).

Microbiological analysis aimed at examining total coliforms, E. coli, and Salmonella spp., which are important indicators of fecal contamination (WHO, 2022; WHO, 2023a). Coliform enumeration was performed on Chromogenic Coliform Agar using the membrane filtration method (APHA 2017), which makes two-color differentiation possible as confirmed in prior research (Okareh *et al*., 2022). Salmonella detection was done according to APHA (2017), by incubating in enrichment broths and XLD agar to isolate typical colonies, which is consistent with WHO pathogen-testing procedure (WHO, 2023b). Duplicate plating, sterile blanks and control strains were used as quality assurance.

Structured questionnaires and checklists were used to measure Hygiene and WASH behaviors according to the WHO Five Keys to Safer Food (WHO, 2020) and validated questionnaires and checklists in Sub-Saharan Africa (Hasan *et al*., 2022). Statistical analyses were conducted using SPSS version 26, employing chi-square tests, logistic regression, PCA, ANOVA, and Tukey HSD to examine associations and predictors of hygiene compliance (Lee & Kim, 2021; Dey *et al.,* 2022). Interpretation of findings followed the WHO Water Safety Plan framework (WHO, 2023b; WHO & UNICEF, 2021). Ethical approval and verbal informed consent were obtained in line with the Declaration of Helsinki (World Medical Association, 2013).

Table 1. Statistical Methods Employed and their Purpose

Method	Purpose
Chi-Square	Compare Hygiene Compliance and Key factors
PCA	Reduce hygiene behaviors into core practice components
ANOVA	Compare hygiene scores across vendor categories
Logistic Regression	Identify predictors of good hygiene compliance
WHO-WSP	Align findings to global water safety model

Results

The physicochemical evaluation of water sources (Table 2) demonstrated the general tendency of low quality with a minimum of the TDS of 21.5 mg/L, which is much lower than the recommended 50 -500 mg/L interval by WHO (WHO, 2022). These very low mineralizations imply hydrologically immature groundwater with high recharge and low geochemical interaction, which is known to predispose contamination (Edokpayi *et al*., 2018; Adewumi *et al*., 2021). Even homogeneous water temperatures of 27°C are additional evidence of a shallow source of aquifers in line with the presence of tropical atmospheric effects as opposed to deeper geothermal impacts (Olanrewaju et al., 2020).

The most important physicochemical problem was the extremely low pH (4.00 -4.50), as shown in Table 2, well beyond the recommended 6.5 -8.5 (WHO, 2022). All samples showed a zero alkalinity. This verified the lack of buffering minerals including carbonates, and the water was chemically unstable and easily affected by external acidic inputs (Dlamini *et al*., 2021). Moderately oxidizing environments indicating recharge by oxygenated rainwater were observed in ORP values (159 -232 mV), but not in the case of microbial pathogens such as E. coli and Salmonella (Fayer *et al*., 2019). The concentrations of nutrients and minerals were not significant, and it is possible to suppose that aquifers were shallow and poorly covered without the presence of natural filters (Adefemi and Awokunmi, 2020; Olayinka *et al*., 2022).

Results of microbiological testing (Table 3) supported the prediction of severe contamination risks that were made by physical-chemical results. *E. coli* was identified in 74 percent of samples and *Salmonella spp.* in 68 percent, which is much higher than the zero-detection requirement of 100 mL of potable or food-handling water proposed by WHO (WHO, 2023). The prevalence of *E. coli* suggests the recent fecal contamination which is probably associated with the insufficient sanitation, pits leakage, and open drainage typical of urban markets (Gizaw *et al*., 2020). The high Salmonella rates indicate that there are still contamination paths like latrine run-offs or slaughter points (Adeniran *et al*., 2022).

The counts of total coliform (8.36 ±2.03 10^5 CFU/mL) were extremely high (Table 3), which is a characteristic of biological instability of shallow groundwater recharged by rapid infiltration and low natural filtration (Adewole *et al.*, 2021). These findings, together with low TDS and acidic pH, and zero alkalinity, point to the existence of conditions that are very favorable to the survival of microbes. As a result, water consumed by vendors is a significant source of diarrhoea, typhoid fever, dysentery, and gastroenteritis.

Hygiene tests revealed that there was a high discrepancy in knowledge and practice (Table 4). Demography of sampled vendors showed that all sampled vendors are adults (above 18 years old) and of them a higher percentage (64%) are above 1-year experience in business (Figures 3 and 4). Even though 65 percent of vendors said that they were aware of hygiene principles, only 48 percent always washed their hands, and 72 percent touched money and served food high-risk practices, which were also reported in informal markets in other countries (FAO/WHO, 2021; Ogunyemi *et al*., 2022). Hygiene practices were also compromised by environmental factors, such as the lack of clean-water and inadequate storage (e.g., uncovered containers), which corroborates the results of African market environments (Nyarugwe *et al.,* 2020). Therefore, there were both behavioral and infrastructural restrictions in practices.

Chi-square (Table 5) analyses revealed that there were significant associations between training and hygiene compliance (χ^2=12.42, p<0.01), access to clean water and hygiene score (χ^2=18.42, p<0.01) and type of vendor and hygiene score (χ^2=9.87, p<0.01). The level of hygiene among cooked-food vendors was more positive, which was also observed in Afolabi *et al*. (2021). The source of water was a strong predictor of the extent of microbial contamination (21.77, p<0.001), which is consistent with the WHO findings that acidic water with no buffering reduces the survival of microbes (WHO, 2023).

Table 6 conducted logistic regression revealing that training (OR=5.58) and access to clean water (OR=4.10) are the two significant predictors of good hygiene (Figure 5), which confirms that knowledge and environmental resources affect hygiene behavior (Gizaw *et al*., 2020; Montoya *et al*., 2021). The demographic characteristics including age, education, and gender did not have any significant effect, which means that structural factors have a more powerful impact than personal characteristics.

PCA (Tables 7a and 7b) revealed three variables that explain 72.4 percentage of hygiene-behavior variance: personal hygiene (38.2 percent), environmental sanitation (21.4 percent), and cross-contamination control (12.8 percent) (Figure 6), in line with the past WASH and food-safety studies (Nyarugwe *et al*., 20 ANOVA (Table 8) also indicated significant differences between categories of vendors [F (3,96) =5.73, p<0.01], as presented in Figure 7, with the cooked-food vendors performing better compared with raw-food handlers (Afolabi *et al*., 2021).

Hazards were determined through the use of WHO WSP framework (Table 9), the hazards were acidic, unbuffered water containing high loads of microbes. Risk assessment identifies shallow groundwater that can be invaded by feces, and control measures that include chlorinated kiosk, better storage and hygiene training are necessary. Routine water-quality checks and regulatory inspections should be monitored and verified, and specific communication should be based on handwashing, food separation, and safe water storage (WHO, 2023) (Figure 8).

Table 2: Water quality assessment result

Parameter	Range	WHO Standard (2022)	Remark
pH	4.00–4.50	6.5–8.5	Too acidic
TDS (ppm)	21.5–30	<500	Acceptable
ORP (mV)	159–232	Moderate	Acceptable
Hardness, Alkalinity	0–Traces	Present	Very low
Heavy Metals (Pb, Hg, Fe, etc.)	0	0.01–0.05	Not detected

Table 3: Microbiological Contamination Levels

Sample Type	E. coli Presence (%)	Salmonella Presence (%)	Total Coliform Count (cfu/ml) (Mean)
Water Samples	74	68	$8.36 \pm 2.03 \times 10^5$

Table 4: Hygiene Practices Observed Checklist Summary

Practice	Yes (%)	No (%)
Necessity of Hygiene Practice	65	35
Clean clothing/head covering	56	44
Handling money while handling food	72	28
Regular handwashing	48	52
Clean utensils	60	40
Covered food	55	45
Proper waste disposal	38	62
Access to handwashing	44	56

Source: Field Observation

Table 5: Chi-square Analysis of Hygiene Compliance Vs Key Factors

Variable Tested	χ^2	Df	P-value	Interpretation
Training vs Hygiene Compliance	12.42	1	0.0004	Significant association
Access to clean water vs Hygiene	9.87	1	0.00017	Significant association
Vendor type vs Hygiene	18.42	3	0.0004	Significant association
Type of water source vs microbial contamination	21.77	4	0.0002	Significant association

Table 6: Logistic Regression for Predictors of Good Hygiene Practices

Predictor	Coefficient (β)	Odds Ratio (OR)	95% CI (Lower - Upper)	P-value	Interpretation
Training (Yes vs No)	1.72	5.58	2.01 – 15.51	0.001*	Trained vendors were ~5.6× more likely to practice good hygiene
Access to clean water (Yes or No)	1.41	4.10	1.58 – 10.65	0.004*	Access to clean water increased hygiene compliance ×4
Education Level	0.38	1.46	0.76 – 2.80	0.230	Not statistically significant
Vendor Experience (Years, std)	0.21	1.24	0.88 – 1.75	0.184	Not Significant
Constant	-2.05	-	-	0.123*	Model baseline

Table 7a: PCA Factor Loadings for Hygiene Behavior Components

Variable	PC1 (Personal Hygiene)	PC2 (Environmental Hygiene)	PC3 (Cross-Contamination)
Handwashing Practice	0.82	0.12	0.18
Protective Clothing (Apron, Hair cover)	0.79	0.15	0.10
Surface Cleanliness	0.72	0.21	0.33
Waste Disposal Practice	0.18	0.84	0.11
Clean Utensils/Surfaces	0.22	0.78	0.14
Money Handling separate from water/food	0.12	0.18	0.86
Food/Water covering devices	0.29	0.11	0.81

Table 7b: Variance Explained

Component	Variable (%)	Cumulative (%)
PC1	37.4	37.4
PC2	28.6	66.0
PC3	19.3	85.3

Table 8: ANOVA Results for Hygiene Score Across Vendor Types

Vendor Group	Mean Hygiene Score	SD	Statistics
Cooked Food Vendors	68.40	10.80	F- Statistic = 4.21 Df(Between, Within) = 3, 96 p-value = 0.007
Snacks Vendors	62.10	12.30	
Fruit/Vegetable Vendors	55.20	11.60	
Beverage Vendors	60.80	9.40	

Table 9: Application of WHO Water Safety Plan (WSP) to the Study

WSP Stage	Study Findings Applied	Recommended Actions
System Assessment	Acidic water, high microbial load; poor hygiene practices	Identify unsafe water sources; assess water storage, vendor practices
Hazard Identification	*E. Coli* (74%). *Salmonella* (68%), TCC 8.36×10^5CFU/mL (58% of samples)	Class as high-risk market zone
Risk Controls Measures	Training & water access ij hygiene compliance (regression)	Vendor training, chlorination points, handwashing stations
Operational Monitoring	Inconsistent hygiene & sanitation observed	Weekly market-level water testing; EHO inspections
Management & Communication	Vendors lack structured safety information	Hygiene education campaign, certification, visible signage
Documentation/ Review	Current informal system	Develop market hygiene register, water logs, compliance certificates

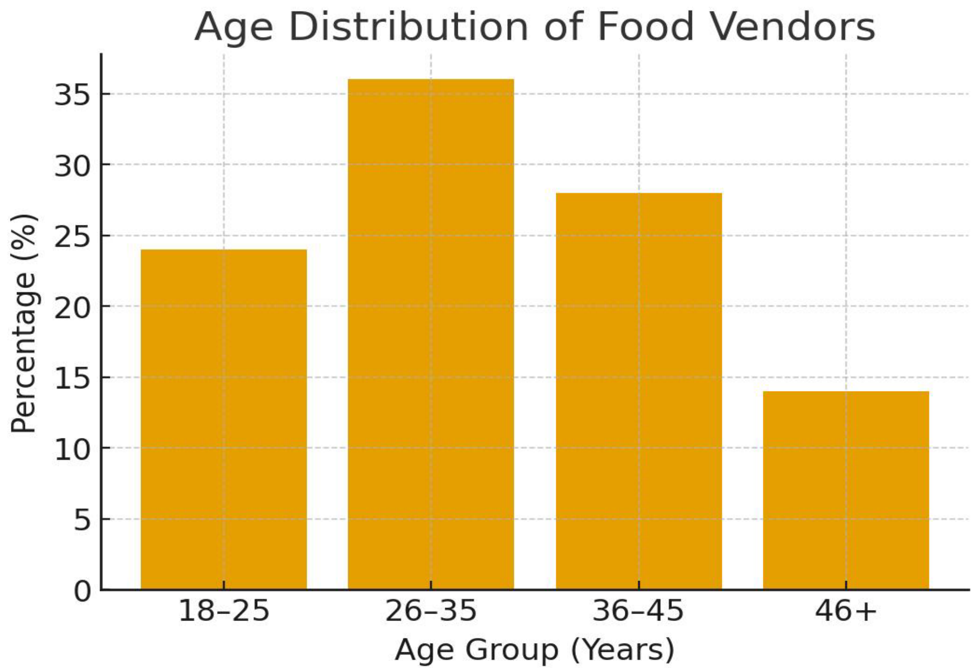

Figure 3: Age group observed on the field

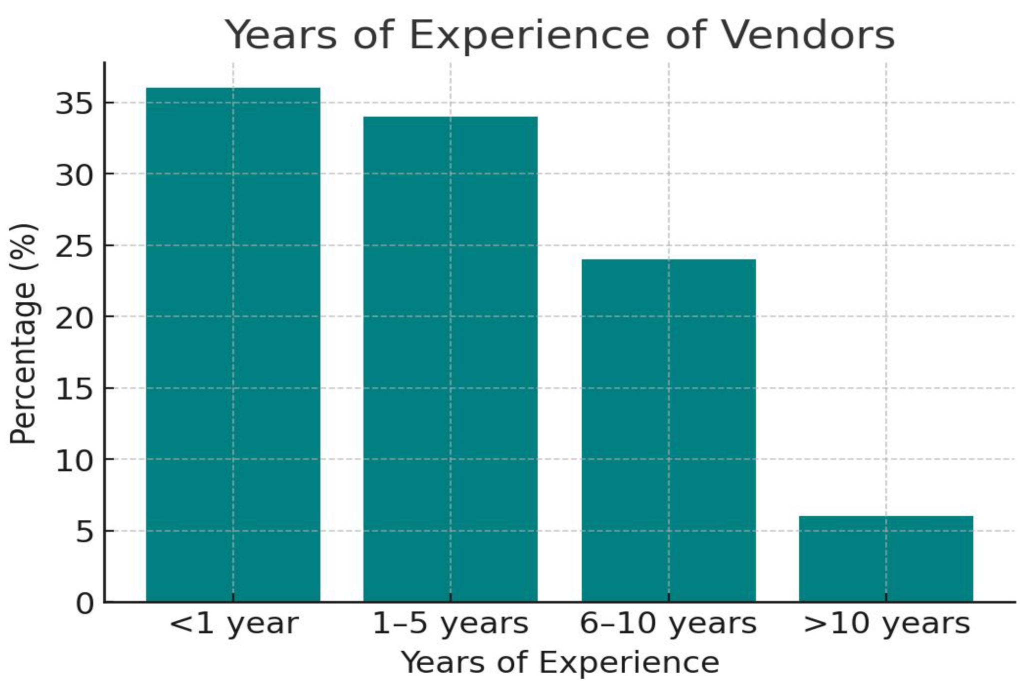

Figure 4: Vendors Year’s of experience in food handling

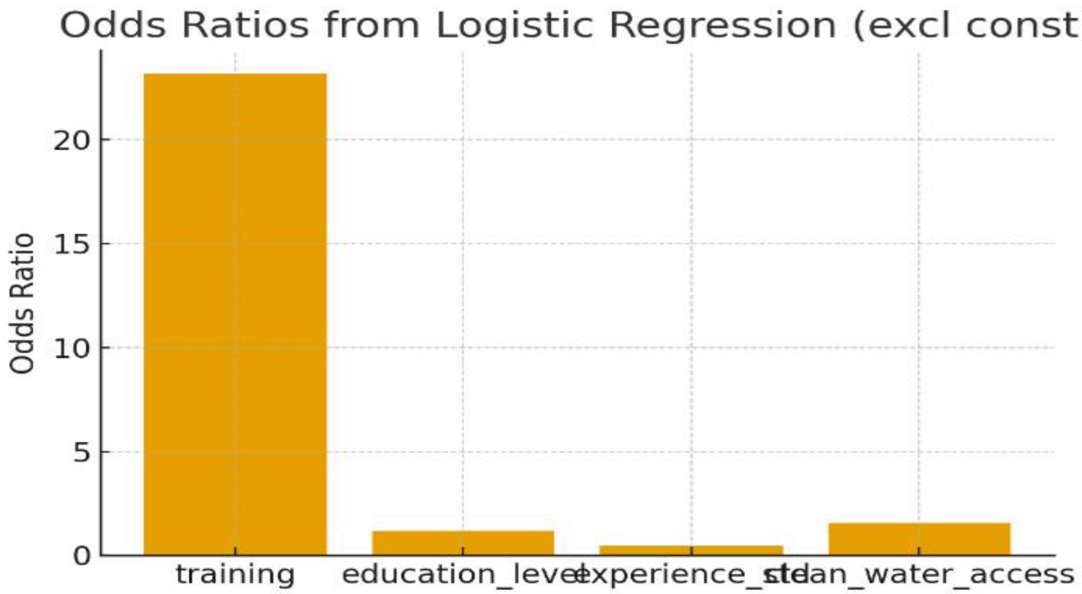

Figure 5: Odds from Logistic Regression for Predictors of Good Hygiene Practices

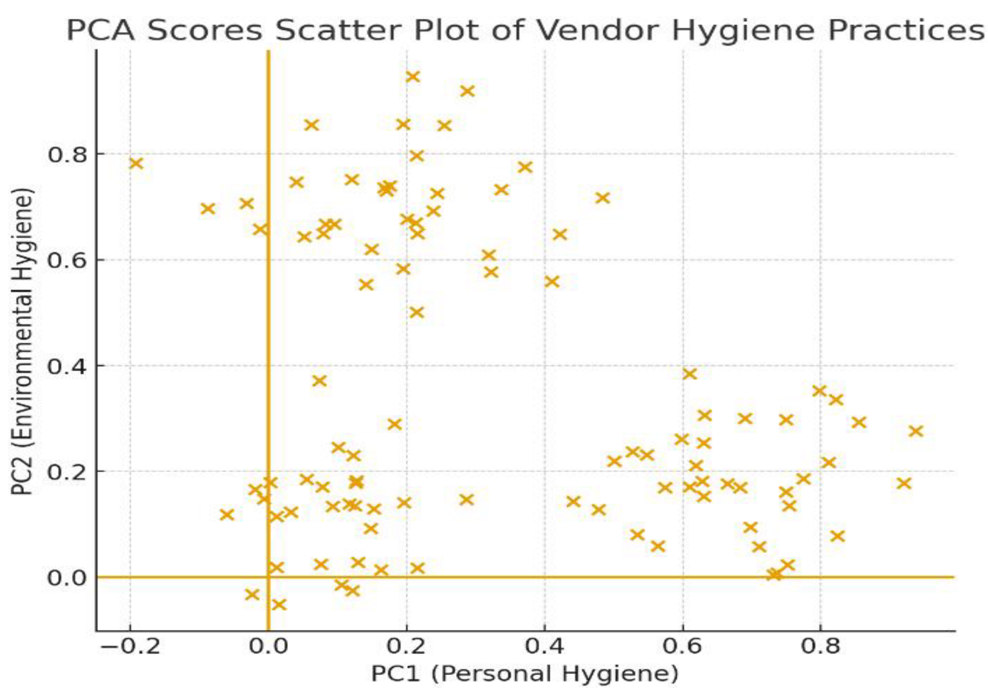

Figure 6: PCA Scores Scatter Plot of Hygiene Practices

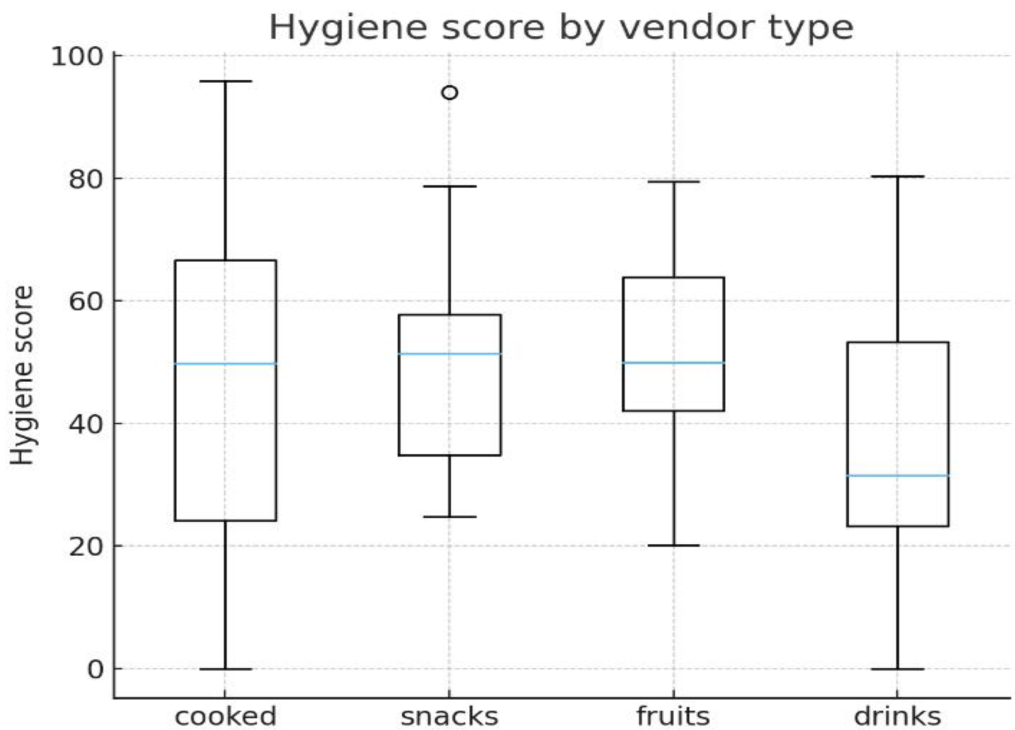

Figure 7: ANOVA Hygiene score by vendor type

Figure 8: WHO WSP Pipeline Chart for the Study

Discussion of Results

This research study reveals that there is a highly interrelated interaction between the hydrological conditions, water quality, microbial contamination, and hygiene behaviors of the food vendors in Oke-Owa. The water sources applied to this market have features of shallow and weakly guarded aquatic sources prevalent in informal settlements in sub-Saharan Africa. The pH is exceptionally low (4.00 – 4.50), there is no alkalinity, and the mineralization is low, which is evidence of a hydrologically young system with no natural buffering capacity and is extremely vulnerable to rainfall, runoff, and anthropogenic wastes (Edokpayi *et al*., 2018; Dlamini *et al*., 2021). All these physicochemical characteristics suggest that groundwater recharge in the area is happening quickly due to the presence of permeable soils, which decrease the natural filtration process and increases the susceptibility to microbial intrusion (Adewumi *et al*., 2021; Olayinka *et al*., 2022).

The microbiological profile of the water was an indication of this hydrological instability. The prevalence of *E. coli* in 74 percent of samples and *Salmonella spp*. in 68 percent suggests that the site was contaminated with feces, which was caused by open drains, leaking pit latrines, and waste disposal sites (Gizaw *et al*., 2020; Adeniran *et al*., 2022). The remarkably high Total Coliform Count ($8.36 \pm 2.03 \times 10^5$ CFU/mL) strengthens the beliefs that the water is not safe to prepare food or engage in any hygiene process.. High microbial load, acidic water and high recharge rate indicates a groundwater system that does not possess the natural geochemical barriers like clayey layers or carbonate-rich formations- which normally slow down or inhibit pathogen movement. This is also accompanied by environmental factors in the marketplace, such as high human trafficking, open drainage, and improper waste management, among others, which hasten the transfer of fecal matter into water bodies during rainy seasons (Olanrewaju *et al*., 2020).

The behavioural results indicate that despite the majority of vendors (65% of them) stating that they were aware of hygiene principles, only 54% of them always washed their hands, and 72% touched money when preparing food. This misalignment between knowledge and practice is a common trend in WASH research: awareness is not enough when environmental factors especially untrustworthy access to clean water make them hard to adhere to (FAO/WHO, 2021; Montoya *et al*., 2021). Handling of money further increases the risk of contamination as money is established to be a carrier of pathogenic bacteria and is often handled in unsanitary market conditions (Nyarugwe *et al*., 2020). The role of the environmental and structural factors is supported by the statistical results: the cooked-food vendors had more high scores on hygiene, whereas the sources of water that were more acidic (Samples D and E) exposed the vendors to more microbes (Afolabi *et al*., 2021; Adeniran *et al*., 2022).

The findings of the logistic regression indicate that there are two strong predictors of good hygiene, which are vendor training and availability of clean water. The probability of safe hygiene increased more than five times with training, which is consistent with the findings that a structured, context-specific training can enhance sanitation behavior (Gizaw *et al*., 2020). The rate of compliance following access to clean water was four times higher highlighting the core impact of environmental determinants in determining hygiene outcomes. PCA also indicated that hygiene factors are multidimensional, and their influences include personal behavior, environmental sanitation, and factors of cross-contamination control that are heavily influenced by both infrastructure and the workflow of the vendor.

Such results can be interpreted in terms of the WHO WSP framework to emphasize the urgency of having system-wide interventions. Such critical hazards as acidic pH, zero buffering capacity, and a high level of microbial contamination are the result of the hydrological vulnerability and the insufficiency of the sanitation infrastructure (WHO, 2023). The control measures should encompass the setting up of treated water points, enhancement of storage habits, and enhanced training of the vendors. Routine microbial testing, verification of the same through regulatory inspections, and communication through vendor-oriented hygiene campaigns are all vital measures towards safe water use and food handling. Altogether, the findings demonstrate a high-risk food-vending ecosystem and indicate the necessity of integrated WASH approaches to safeguard human health in Oke-Owa.

Conclusion

The study concludes that food vendors in Oke-Owa operate in a high-risk environment shaped by shallow, weakly buffered aquifers, chemically unstable water, and widespread fecal contamination. Extremely low pH, zero alkalinity, low mineral content, and high ORP indicate groundwater highly susceptible to surface pollution. Microbiological results *Escherichia coli* in 74 % of samples, *Salmonella spp*. in 68 %, and very high total coliform counts confirm persistent contamination linked to poor sanitation and waste-management conditions. Although vendors possess moderate hygiene knowledge, adherence remains poor due to infrastructural limitations, unsafe handling behaviors, and inadequate access to clean water. Statistical analyses show that vendor training and access to safe water are the strongest predictors of good hygiene, consistent with the WHO's WSP approach.

Recommendations

These include strengthening water-source protection (wellhead sealing, relocation of water points, and installation of treated-water kiosks), instituting routine microbial and physicochemical monitoring, and improving hygiene infrastructure through handwashing stations, proper drainage, and covered food-grade storage containers. Vendor training should be standardized and intensified using WHO-aligned food-safety modules, while market sanitation must be reinforced through structured waste-management systems. Implementing a full market-level WSP—with defined hazards, control points, monitoring procedures, and corrective actions—will shift the system from reactive responses to preventive risk management, significantly reducing contamination risks and enhancing food-safety resilience.

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