Risk assessment of hand-dug well water: A case study of Aflao in Ghana

Abdul, S.*[1], Dwumfour-Asare, B.*[2], Mensah, G. T.[3] and Owusu-Mensah, I.[4]

[1]*Department of Public Health Education, Faculty of Environment & Health Education, AAMUSTED. Asante Mampong Campus,Environmental Health and Sanitation Unit,Volta Region*

[2]*Department of Environmental Health and Sanitation Education, Faculty of Environment & Health Education, AAMUSTED. Asante Mampong Campus*

[3]*Council for Scientific and Industrial Research, Water Research Institute, Accra*

[4]*Department of Integrated Science Education, Faculty of Science Education, AAMUSTED. Asante Mampong Campus*

*Authors for correspondence: sumailaabdul001@gmail.com/ *bdasare@aamusted.edu.gh*

ABSTRACT

Peri-urban and rural areas in developing countries like Ghana face challenges with access to quality potable water due to increasing groundwater contamination risks. This study assessed the risk of hand-dug well (HDW) water in Aflao using a cross-sectional survey of 400 wells based on WHO sanitary inspection checklists.Water samples from 20 wells were analysed for microbial contamination and heavy metals (Pb, Cd, Cr, Ni, As) using membrane filtration and Atomic Absorption Spectrometry. Results revealed that 37.3% of wells were within 10 meters of latrines, 98% lacked concrete floors, 98.3% lacked covers, 88.5% had poor drainage, 31.8% were under trees, and all were shallow (<30m). Microbial loads exceeded WHO guidelines(0 cfu/100ml): total coliforms (579.7 ± 294.9 CFU/100 ml), faecal coliforms (32.6 ± 54.7 CFU/100 ml), and *E. coli* (14.7 ± 21.7 CFU/100 ml) were detected in all samples.Sanitary risk factors, including latrine proximity, absence of covers, poor drainage, and shallow depth, were significantly associated with microbial contamination ($p<0.05$; OR>1) . Heavy metals were below detection limits (0.001–0.01 mg/l). Poor microbial quality and its association with sanitary risks confirmed that HDWs in Aflao are unsafe for consumption without treatment.

Keywords: Contamination, groundwater, hand-dug wells, health risk assessment, sanitary inspection.

HIGHLIGHTS

- Majority of hand-dug wells failed the WHO sanitary risk assessment criteria
- Wells exposed to specific risk factors had a higher likelihood of microbial contamination
- Heavy metals in wells were below minimum detection limits.
- Microbial contaminants were detected in a majority of the hand-dug well water samples
- Well water is unsafe for consumption without treatment against potential pathogens

GRAPHICAL ABSTRACT

RISK ASSESSMENT OF HAND-DUG WELL WATER: A CASE STUDY OF AFLAO IN GHANA

Problem: Aflao relies on hand-dug wells (HDWs) for water, with about 70% of the population depend on HDWs due to the challenges faced by their public water supply (GSS, 2021). Their shallow depth and presence of potential contamination sources and factors make them vulnerable to microbial and chemical contamination (Xue et al., 2020), posing health risks.

Aim: This study assessed the risk of hand-dug wells in Aflao, Ghana

Methods

Data collection

1. Sanitary risk assessment (SRA) of HDWs using WHO observational checklist.

2. HDWs sample collection for microbial and Heavy metal analysis.

Results

Analytical report of microbial organism

		Cfu/100ml				
Zones	N	TC	FC	*E.coli*	*Salmonella*	*Shigella*
Z A	5	489.6	22.2	7.8	0	0
Z B	5	539.4	45	13.8	0	0
Z C	5	527.2	5.6	3.8	0	0
Z D	5	762.6	57.6	33.4	0	0
Total		579.7	32.6	14.7	0	0

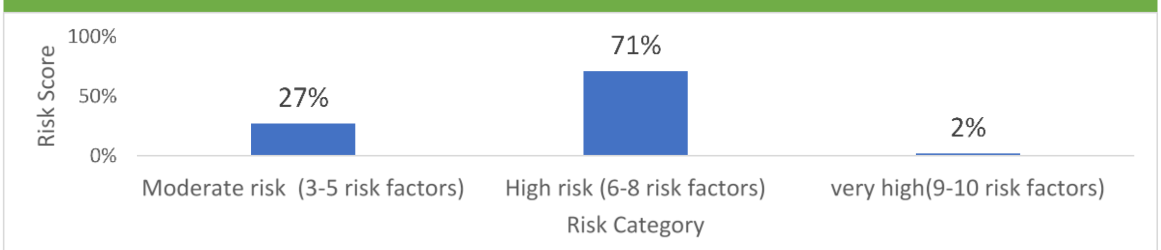
WHO standard (0 cfu/100ml)

Analytical report of heavy metals

Zones	**N**	**Pb (mg/l)**	**Cd (mg/l)**	**Cr (mg/l)**	**Ni (mg/l)**	**As (mg/l)**
ZA	5	<0.005	<0.002	<0.01	<0.01	<0.001
ZB	5	<0.005	<0.002	<0.01	<0.01	<0.001
Z C	5	<0.005	<0.002	<0.01	<0.01	<0.001
Z D	5	<0.005	<0.002	<0.01	<0.01	<0.001
MDL		0.005	0.002	0.01	0.01	0.001
WHO safe limit		0.01	0.003	0.05	0.02	0.01

MDL: Minimum Detection limits

Sanitary Risk Scoring of HDWs



Conclusion

The study identified Sanitary risk factors and their influence on microbial contamination of HDWs. Heavy metals were below minimum detection limits (0.001–0.01 mg/L). Hence, HDWs were unsafe for consumption without treatment.

INTRODUCTION

High population growth, rapid economic development, and urbanization have exerted significant pressure, particularly in developing countries, on the inadequate conventional piped water supply systems (Amin *et al*., 2019). As a result, millions of people are left behind without access to safe water services, making them vulnerable to a range of preventable illnesses affecting the quality of life and also undermining the fundamental human rights to safe water for economic development (WHO, 2023). Nearly 2 million deaths and 123 million disability-adjusted life years are linked to inadequate access to safe water, and 2 billion global population lack access to safe and reliable sources of water (WHO, 2023). This pressing global issue of water accessibility is more pronounced in developing countries, especially in Sub-Saharan Africa (Ogunbode *et al*., 2024).

The coping strategies with inadequate formal and/ or conventional piped water systems in communities in developing countries are reliance on groundwater sources through developing boreholes and hand-dug wells (HDWs) (Cid Escobar, 2024). Boreholes are typically deeper and better protected and therefore are generally regarded as safer options (Rauf *et al*., 2021). Most HDWs are unprotected wells and are considered unsuitable for consumption due to the high risk of contamination from surface runoff, nearby sanitation facilities, and other environmental factors (Addo *et al*., 2023; Kupa *et al*., 2024). Despite these safety concerns, many areas continue to rely on HDWs as a primary water source because of their affordability, ease of construction, and lack of access to more secure alternatives like boreholes or treated piped water systems (Malinga and Hashe, 2024). In many developing countries, HDWs serve as essential water sources, particularly in rural areas of Sub-Saharan Africa and parts of Asia (Zhang *et al*., 2020).

According to the Ghana Statistical Service (2021), 12% of the Ghanaian population relies on unprotected HDWs for their water needs.The Ghana National Water Policy recognises access to safe water as a basic human right including protection of unprotected sources like HDWs (Ministry of Sanitation and Water Resources,2024). The policy also mandates water safety measures such as integration into national planning, regularly prepare and review national and Integrated Water Resources Management (IWRM) plans, promote practices that protect critical natural resources and prevent irreversible ecological damage and the "polluter pays" principle to address ground and surface water contamination, ensuring equitable access and inclusive management for all, especially marginalized groups.

Most Ghanaian HDWs are unprotected with significant risk of environmental contamination (Addo *et al*., 2023). For instance, the absence of centralized wastewater treatment systems in many towns and communities has led to the proliferation of private on-site sanitation facilities (Asumadu *et al*., 2023). These cluster of sanitation facilities pose a significant risk of contaminating groundwater through the infiltration of wastewater with contaminants like pathogens, heavy metals and others (Addo *et al*., 2023). Evaluating the microbial and physicochemical quality of HDWs is crucial because it provides insights into the risk associated with harmful contaminants that are threat to public health (Kushwah and Singh, 2024). HDWs could pose significant health risk mostly because they are highly susceptible to microbial and chemical contamination (Xue *et al*., 2020), Yet, there are inadequate studies in Ghana on the risk associated with HDW water sources especially in larger towns especially where such wells serve as the main water supply sources.

Afloa, one of the busy border towns in Ghana within the Ketu-South Municipality main water source is HDW (Amoako *et al*., 2023). There is limited information like in other towns on the risk associated with the HDW water sources. This study therefore assessed the risk of the HDW water source in Aflao to provide an understanding of sanitary risk factors using the World Health Organization (WHO) observation checklist.

MATERIALS AND METHODS

Study Area

Ketu-South Municipal is a low-lying area that ranges in elevation from 66 metres inland to less than 15 metres close to the coast. The coast is smooth and dotted with sandbars. The municipality's drainage system is dominated by seasonal streams and flows southward to Aflao (Babanawo *et al*., 2022). The average annual precipitation is 850 millimetres at the coast and 1,000 millimetres inland, with a double rainfall peak from April to July and September to October. The dry season, from December to February, is marked by harmattan winds. Rainfall during the minor season is low and unpredictable, particularly between Agbozume and Aflao (Babanawo *et al*., 2022). The hydrogeology includes recent and tertiary formations of unconsolidated sands and clays, as well as partially consolidated red continental deposits of sandy clay and gravel. Beneath newer coastal sediments lies a thick layer of marine sands, clay, shale, limestone, sandstone, and some gravel (Amoako *et al*., 2023).

In addition to its unique terrain, Aflao was chosen for this study because it is one of the busy large towns in Ghana with majority of its population (70%) relying heavily on hand-dug wells (HDWs) (GSS, 2021) due to persistent challenges with public water supply.

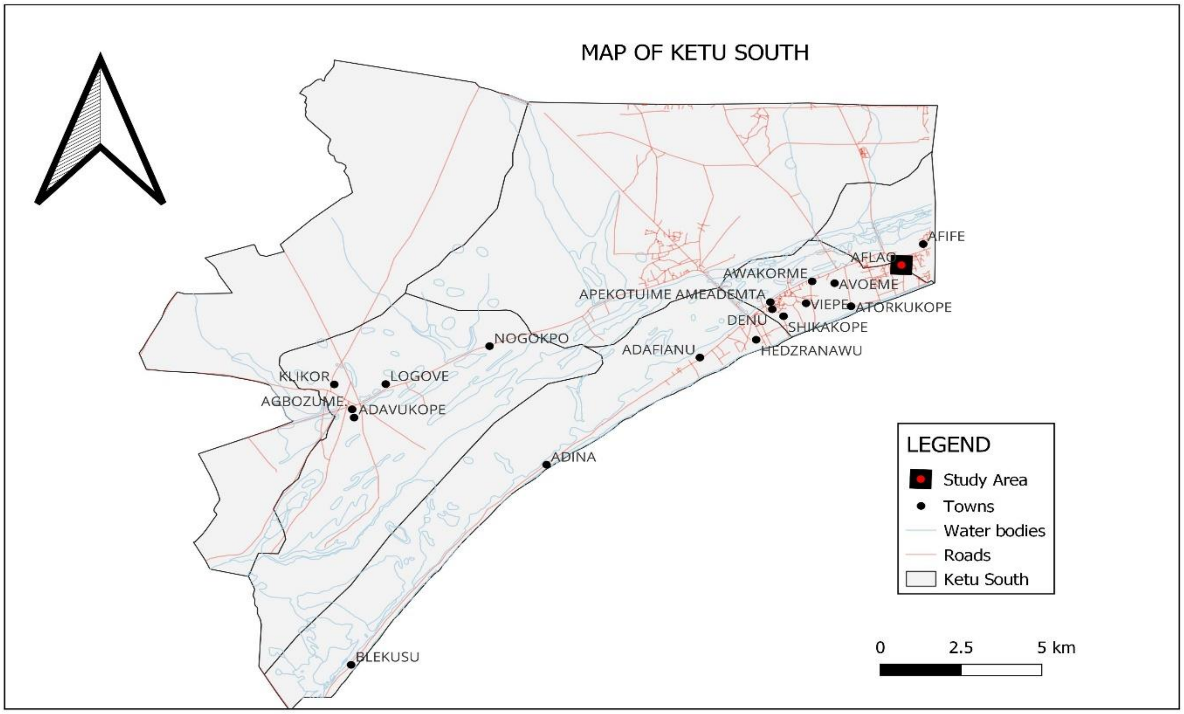


Figure 1: Ketu South Municipal Assembly map showing the study town - Aflao

Sampling and Data Collection

The study used a cross-sectional survey approach. The World Health Organization (WHO) checklist was used for the Sanitary Risk Assessment (SRA) of the HDWs, along with laboratory analyses of water samples from HDWs.

Given a total of 6,046 HDWs, a sample size of 375 was determined using Yamane (1973) simplified sampling formula (Equation 1 below) with the assumptions of 95% confidence level, 5% desired level of precision, and 50% maximum variability (Israel, 1992). However, the sample size was approximated to 400 for improvement in reducing sample error (Etikan and Babtope, 2019). This formula was adapted as HDWs were considered as human population. Hence 400 samples were obtained and equally distributed (100 samples each) to four zones in the Aflao community for the SRA. Additionally, the study purposively collected 20 water samples from 5 HDWs samples from the four zones with the selection criteria based on the location as: (1) Two wells from water-prone areas, and (2) three wells from dry-up land areas. Waterlogged areas tend to have higher risks of contamination due to stagnation and surface runoff, while dry-up land areas are more susceptible to groundwater depletion and potential concentrations of contaminants (Zhao *et al*., 2024). The decision of considering higher number of wells in the dry-up area was based on the high number of wells, sanitary risk factors like household/public toilet, and refuse dump in that areas than the waterlogged area.This selection allows for a comparative analysis of water quality under varying environmental conditions, providing a broader understanding of potential contamination sources and risks.

$$n=\left(\frac{N}{1+N(e)^2}\right) \qquad \text{Equ 1 (Yamane,1973)}$$

where, N = population of HDWs (6,xxx); e = desired level of precision (5%)

Sanitary inspections

A sanitary risk survey was conducted to determine the sanitary risk factors of 400 hand-dug wells in Aflao, using WHO guidelines which involved identifying potential factors and sources of contamination. The sanitary inspection technique was adopted from the WHO Guide for Drinking Water Quality standard having a systematic checklist of a small number of specific inquiries (WHO, 2024). This checklist addressed the 10 most fundamental potential sources and factors of well water contamination.

Water sample collection and Laboratory analyses

Water sample collection

Water samples were collected from 20 HDWs using 500 ml sterilized plastic bottles and transported to the Council for Scientific and Industrial Research (CSIR) -Water Research Institute laboratory in Accra within 24 hours under a controlled temperature of 4°C in an ice-chest box during transportation following the protocol in APHA (1989).

Heavy metal analysis

Atomic Absorption Spectroscopy (AAS) *(Table 1)* was employed to determine the concentration of metals (Lead [Pb], Cadmium [Cd], Chromium [Cr], Nickel [Ni], and Arsenic [As]) by using the protocol of APHA (1989). Sample solution was aspirated into flame and atomized. Through the flame, a light beam was focused, passing through a monochromator and onto a detector that determined how much light the flame absorbed. Since each metal has its characteristic absorption wavelength, a source lamp composed of that metal was used. The amount of energy at the characteristic wavelength of 279.5nm absorbed in the flame was proportional to the concentration of the element in the sample over a limited concentration range.

Table 1: Heavy metals reagent identification

Type of kit	Manufacturer	Element	Batch number	Article number
Single-Element AAS-Standard-Solution	Carl Roth GmbH + Co. KG	Lead	811498	2228.1
		Cadmium	809969	2238.1
		Chromium	805735	2250.1
		Arsenic	811497	2224.1
	Surechem Products	Nickel	19242/2a	N1702

Microbial analysis

Membrane filtration was used, employing a sterile 0.45μm Millipore filter, Erlenmeyer flask, and vacuum source. Samples were filtered and placed on selective media, including Xylose Lysine Deoxycholate (XLD) Agar for *Shigella* and *Salmonella*, M-FC for faecal coliforms (FC), total coliforms (TC) and Hi-Chrome agar for *E. coli*, all in separate Petri dishes. Incubation occurred at 37±2 °C for 18-24 hours for the analysis. Clamps and forceps were sterilized before each use. All these procedures and techniques followed the APHA Standard Methods for the Examination of Water and Wastewater (APHA, 1989).

Data analysis

Following Viban *et al*. (2021), regression analysis was used to examine the link between detected organisms and observed risk factors/sources, specifically utilizing the beta Poisson model. In our approach, 'No' responses to sanitary risk factors were assigned "absence of a risk factor" and taken as the reference categories in the statistical analysis, allowing for a comparison with the 'Yes' responses, which indicated the presence of a risk factor. This involved the use of odds ratios (OR) and a 0.05 significance level. As demonstrated by Viban *et al*. (2021), an OR below one suggested no significant difference between contamination and observed risk factors. Conversely, an OR exceeding one indicates an association with the specific risk factor under consideration, while an OR of one implies no discernible difference between contamination and observed factors. Sanitary Risk Assessment (SRA) was obtained through the adoption of the WHO SRA checklist for well water. Household scores 9-10 risk factors indicate a "very high risk," while 6-8 signifies "high risk," 3-5 denotes "moderate risk, "1-2 suggests "low risk," and 0 "no risk".The statistical tool employed for the analysis was Statistical Package for Social Sciences version 27.

Health risk assessment associated with heavy metals

Health risk assessment for heavy metals (HMs) involves the use of guideline limits, and models such as Hazard Quotient (HQ), Hazard Index (HI), and the Lifetime Cancer Risk (LCR) model for carcinogenic risks. The HQ evaluates non-carcinogenic effects and HI which is the sum of all HQ values for different metals, provides a cumulative risk assessment with values below "1" indicating no significant risk. If the HI value is less than 1, there is no significant risk of combined health effects (Balogun *et al*., 2023). The LCR model estimates the probability of developing cancer over a lifetime due to exposure to metals like As, Cd, Cr, and Ni.

RESULTS

Household characteristic

The surveyed population, comprised of 400 respondents, exhibited a diverse demographic profile with an average age of 46 and a gender distribution of 76% females and 24% males. Education levels varied, ranging from 38% with no formal education to 3% attaining tertiary education. Employment diversity was notable, with 31% not employed, including about 7% retirees, 61% self-employed predominantly traders, and 8% in government positions. The average household size was 3, and residents had, on average, lived in the community for 20 years, occupying houses with an average size of 9 people. All the assessed wells were privately owned by households and fully depended on for their domestic and drinking purposes.

Sanitary Risk Assessment (SRA)

The results of the SRA conducted on 400 hand-dug wells are presented in Table 2**.** The findings indicate that several sanitary risk factors were widespread and needed to be addressed. The absence of a concrete floor around wells was noted in 94.5% of cases, while shallow well depths of less than 30 metres and the incorrect handling of ropes and buckets were present in all wells studied (100%). Also, the absence of covers for wells was documented in 98.25% of wells, and insufficient drainage systems were noted in 88.5% of wells. These factors, due to their high prevalence, represent critical areas requiring urgent intervention to ensure the safety of water from these wells. However, some sanitary risk factors, while less prevalent, still pose significant concerns and should not be overlooked. The presence of latrines within 10 metres of the wells was identified in 37.3% of the wells, and 20.8% were located below latrines positioned on higher ground. Wells surrounded by animal excreta or rubbish within a 10-metre radius accounted for 35.3% of the total, and 31.8% were located near or under trees, which may contribute to organic debris and animal droppings entering the water. Inadequate construction of well headwalls, observed in 7.8% of cases, represents a less common but concerning issue that may allow surface water to contaminate the wells. While all the factors assessed permit attention to reduce contamination risks, it is evident that issues such as the absence of concrete floors, shallow well depths, improperly handled ropes and buckets, absence of covers, and poor drainage systems should be prioritized due to their higher prevalence and immediate threat to water quality. Factors with lower prevalence, such as proximity to latrines, trees, or rubbish, and inadequate headwalls, though less urgent, remain essential to address for long-term water safety improvements.

Table 2: Sanitary risk assessment

		Distribution	
S/N	***WHO Sanitary risk factors assessed***	***Yes (N=400)***	***%***
1	Latrine within 10 m of the well	149	37.3%
2	Latrine uphill/nearest latrine on higher ground than the well	83	20.8%
3	Animal excreta or rubbish within 10 m of the well	141	35.3%
4	Absence of drainage/poor drainage system	354	88.5%
5	Well under or closer to a tree	127	31.8%
6	The well headwall is inadequate, likely to allow surface water to enter the well	31	7.8%
7	Absence of concrete floor around the well	378	94.5%
8	The depth of the well is Shallow (less than 30m)	400	100.0%
9	Ropes and buckets left in such a position that may become contaminated	400	100.0%
10	Well, requires a cover	393	98.25%

Sanitary Risk Scoring (SRS)

The SRS revealed a significant proportion of wells falling into higher-risk categories. Specifically, 2% of the wells were classified as very high risk, while 71% were categorised as high risk, collectively accounting for 73% of the wells (Figure 2). This result indicated that nearly three-quarters of the wells were at substantial risk of contamination, emphasising a critical need for targeted interventions. The remaining 27% of the wells fell into the moderately risky category, which, although comparatively lower, still represents an alarm for potential contamination.

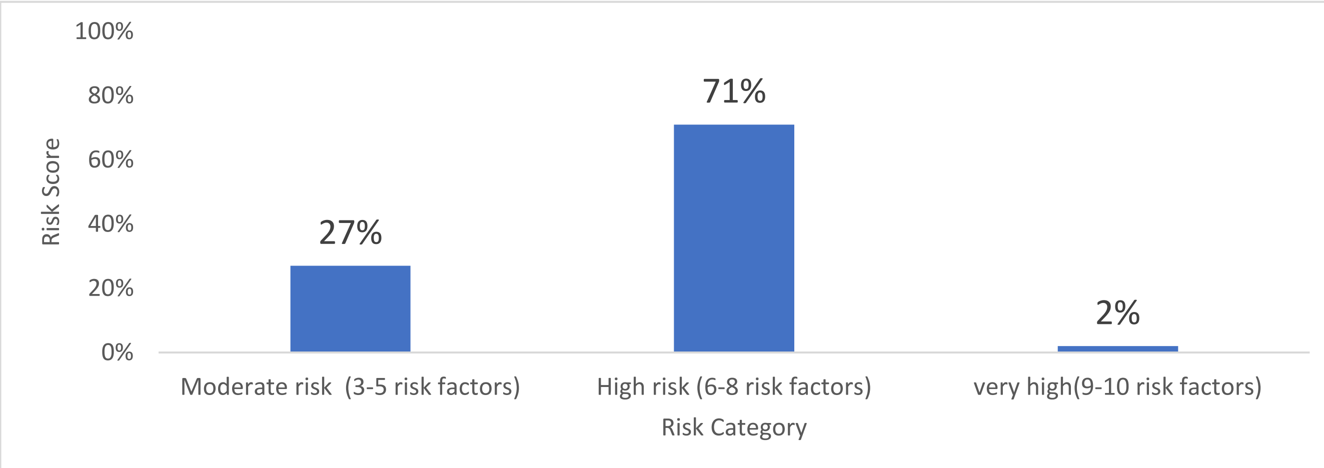


Figure 2: sanitary risk scoring

Observed sanitary risk factors versus microbial loads

The mean concentration of total coliform was 579.7.00 CFU/100ml with a standard deviation (SD) of 294.9 CFU/100ml, indicating considerable variability among the samples. Faecal coliform had a mean of 32.6 CFU/100ml and a SD of 54.7 CFU/100ml, while *E. coli* recorded a mean concentration of 14.7 CFU/100ml with a SD of 21.7 CFU/100ml. *Salmonella* and *Shigella* were absent in all the samples (*Table 4)*. The proximity of latrines within 10 metres of a well, areas prone to flooding, and public toilet areas, as well as wells located under trees, wells designated for public use, latrines situated uphill from wells, the practice of digging and burying faeces within households, and the absence of proper drainage and well covers were significantly associated ($p < 0.05$) with increased levels of microbial contamination (*Table 3)*. However, the presence of animal droppings did not show a significant association with contaminant levels ($p > 0.5$), nor did the presence of public toilets correlate with TC levels. Similarly, the absence of well covers, flood-prone areas concerning *E. coli*, and the practice of digging and burying faeces of *E. coli* were not significantly associated with contamination.

Key risk factors with higher OR (OR > 1) indicating a strong association with contamination included the presence of latrines within 10 metres of a well (average distance between 8 households with septic tank toilets and observed well water was 6m, with 10 to 11m**)**, which showed significantly increased odds for faecal coliforms (OR = 5.620, CI=4.114-7.678), total coliforms (OR = 1.247, CI=1.183-1.313), and *E. coli* (OR = 2.699, CI=1.799-4.051) contamination. Wells located under trees were also strongly associated with contamination, with OR and CI values of 1.890 and 1.220-2.928 for faecal coliforms and 2.806 and 1.524-5.168 for *E. coli*. Additionally, wells designated for public use showed 2.516 times more likely to contaminate the well water with FC and 3.591 for *E. coli*. Latrines situated uphill from wells exhibited increased odds of contamination with OR values of 3.034 for FC and 1.710 for *E. coli*. The absence of a fence, cover, apron and shallow well with an average of depth 3.84m and water levels at 3.35 exhibited constant outcomes, with all observations and measurements consistently yielding the same result (risk factor observed). This implies that observed factors did not exhibit variation or fluctuation within the dataset. The unidirectional skewness of these constant observations and measurements suggests a lack of diversity or meaningful variability in the specific attributes assessed within the studied population as indicated in dash (-) in *Table 3*.

Table 3: Observed sanitary risk factors versus microbial loads

	Faecal coliform			Total coliform			*E. coli*		
Risk factors	CI	OR	P-value	CI	OR	P-value	CI	OR	P-value
Latrine within 10m to a well =YES	4.114-7.678	5.620	.000	1.183-1.313	1.247	.000	1.799-4.051	2.699	.000
Latrine within 10m to a well =NO		1	-		1	-		1	-
Absence of drainage system =YES	0.160-0.333	.231	.000	0.601-0.673	.636	.000	0.234-0.601	.375	.000
Absence of drainage system =NO		1	-		1	-		1	-
Absence of cover=YES	0.332-0.678	.475	.000	1.698-1.923	1.807	.000	0.531-1.320	.837	.444
Absence of cover=NO		1	-		1	-		1	-
Flooded=YES	0.556-0.814	.672	.000	1.497-1.654	1.574	.000	0.834-1.457	1.102	.493
Flooded=NO		1	-		1	-		1	-
Well within the vicinity public toilet =YES	0.226-0.441	.315	.000	0.935-1.039	.986	.590	0.274-0.654	.423	.000
Well within the vicinity public toilet =NO		1	-		1	-		1	-
Well under tree=YES	1.220-2.928	1.890	.004	0.574-0.677	.623	.000	1.524-5.168	2.806	.001
Well under tree=NO		1	-		1	-		1	-
Animal faeces and refuse =YES	0.998-1.863	1.364	.051	0.963-1.087	1.023	.460	0.648-1.589	1.015	.948
Animal faeces and refuse =NO		1	-		1	-		1	-
Public use=YES	1.705-3.712	2.516	.000	0.520-0.613	.564	.000	2.005-6.433	3.591	.0 00
Public use=NO		1	-		1	-		1	-
Latrine upward to well=YES	2.139-4.304	3.034	.000	1.130-1.284	1.205	.000	1.076-2.719	1.710	.023

Latrine upward to well=NO		1	-		1	-		1	-
Dig and burry faeces in the house =YES	1.123-2.345	1.623	.010	0.713-0.853	.780	.000	0.532-1.548	.907	.721
Dig and burry faeces in the house =NO		1	-		1	-		1	-
Absence of fence= NO		1	-		1	-		1	-
Absence of apron=YES		1	-		1	-		1	-
Depth (less than 30m) = YES		**1**	**-**		**1**	**-**		**1**	**-**

Table 4: Analytical report of microbial organism

Zones	**N**	TC	FC	*E.coli*	*Salmonella*	*Shigella*
Zone A	5	489.6	22.2	7.8	0	0
Zone B	5	539.4	45	13.8	0	0
Zone C	5	527.2	5.6	3.8	0	0
Zone D	5	762.6	57.6	33.4	0	0
Total		579.7	32.6	14.7	0	0
		WHO	**standard**	0 cfu/100ml		

Pointing out the specific trend illustrated in *Table 5*, the analysis of the *E. coli*, Total and Faecal coliform variable discovered that there were no statistically significant ($p>0.05$) differences observed between any of the zones.

Table 5 :Comparing indicated organisms among zones

Organisms		Zones	Sig.
Total Coliform	ZONE A	ZONE B	.795
		ZONE C	.844
		ZONE D	.167
	ZONE B	ZONE A	.795
		ZONE C	.949
		ZONE D	.254
	ZONE C	ZONE A	.844
		ZONE B	.949
		ZONE D	.230
	ZONE D	ZONE A	.167
		ZONE B	.254
		ZONE C	.230
Faecal Coliform	ZONE A	ZONE B	.522
		ZONE C	.640
		ZONE D	.325
	ZONE B	ZONE A	.522
		ZONE C	.275
		ZONE D	.722
	ZONE C	ZONE A	.640
		ZONE B	.275
		ZONE D	.155
	ZONE D	ZONE A	.325
		ZONE B	.722
		ZONE C	.155
E.coli	ZONE A	ZONE B	.653
		ZONE C	.764
		ZONE D	.068
	ZONE B	ZONE A	.967
		ZONE C	.870
		ZONE D	.462
	ZONE C	ZONE A	.990
		ZONE B	.870
		ZONE D	.150
	ZONE D	ZONE A	.246
		ZONE B	.462
		ZONE C	.150

Health risk assessment of heavy metals

The results of the heavy metals (HMs) analysis from all 20 samples consistently showed concentrations below the minimum detection limits (Table 6): Pb (<0.005 mg/L), Cd (<0.002 mg/L), Cr and Ni (<0.010 mg/L), and As (<0.001 mg/L).

Table 6 : Analytical report of heavy metals

Zones	N	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)	Ni (mg/L)	As (mg/L)
Zone A	5	<0.005	<0.002	<0.01	<0.01	<0.001
Zone B	5	<0.005	<0.002	<0.01	<0.01	<0.001
Zone C	5	<0.005	<0.002	<0.01	<0.01	<0.001
Zone D	5	<0.005	<0.002	<0.01	<0.01	<0.001
MDL		0.005	0.002	0.01	0.01	0.001
WHO safe limit		0.01	0.003	0.05	0.02	0.01

MDL: Minimum Detection limits

DISCUSSION

Microbial and chemical contamination of groundwater sources is a documented issue globally, often linked to poor sanitary conditions around sources (Amoako *et al*., 2023 ; Baia *et al*., 2022). Consistent with our findings, Anang *et al*. (2023) in Ghana observed significant microbial contamination levels in wells situated near sanitation facilities in a community. Similar patterns have been reported in China, where proximity to sanitation facilities emerged as a significant risk factor for contamination (Xue *et al*., 2020). In contrast, studies in Southeast Asia (Cao *et al*., 2021) reported lower contamination levels, likely reflecting differences in well-protection measures and sanitation infrastructure. These variations highlight the influence of regional factors such as hydrogeology, sanitation practices, and community behaviour on groundwater contamination.

The high frequency of microbial contamination of HDWs in the current study can be attributed to various factors, including environmental conditions and infrastructure limitations. Key predictors include the proximity of wells to latrines, lack of concrete floors and well covers, insufficient drainage systems, and the placement of wells under trees (Xue *et al*., 2020). These factors significantly ($p < 0.05$, $OR > 1$) increase contamination risks, as evidenced by the high levels of total coliform (mean=579.7), faecal coliform (maen=32.6), and *E. coli* (14.7) observed in this study *(Table 3)*. Similar findings were reported by Anang *et al*. (2023), who linked faecal contamination in peri-urban Ghana to inadequate separation between sanitation facilities and water sources.

Cultural and environmental sanitation practices also influence contamination risks. In peri-urban communities characterized by slums or informal settlements, maintaining regulatory distances between wells and sanitation facilities is challenging due to limited space, hydrogeological variability, and cultural norms (Oyeniyi, 2020;

Bhallamudi *et al*., 2019). These challenges are compounded by poor maintenance of sanitation systems, as argued by Jenifer and Jha (2022) in India, where design flaws and substandard maintenance exacerbated groundwater contamination, regardless of proximity (Othoo *et al.*, 2020).

The findings of this study aligned with several local investigations on HDW contamination in Ghana and global. For instance, Yousuf *et al.* (2021) identified poor sanitary conditions as a key driver of microbial contamination in wells across peri-urban US, consistent with our finding of high mean score of *TC* (579.7.00 CFU/100ml), FC (32.6 CFU/100ml), and *E.coli* (14.7 CFU/100ml) *(Table 4)* contamination. Similar to our findings, Houéménou *et al*. (2020) reported significant contamination in wells located near latrines and septic systems, suggesting a shared challenge of inadequate separation between water sources and sanitation facilities. In agreement with this study, Lutterodt *et al*. (2018) found that microbial contamination in HDWs was often linked to effluent seepage from on-site sanitation systems, particularly in densely populated areas. This underscores the difficulty of maintaining regulatory distances in communities with limited land availability and poor spatial planning.

This study also discovered additional risk factors, such as the placement of wells under trees and the lack of well covers and concrete floor, shallow well and high water tables which may influence contamination of HDWs. These structural deficiencies are often overlooked in local studies but are critical for addressing water safety concerns **(**Braimah *et al*., 2021). Furthermore, seasonal factors such as heavy rainfall worsen contamination risks. Floods during the rainy season easily contributes to contamination through leaching of contaminants, as documented by Cao *et al*. (2021), and this effect was further supported by Nascimento Santos *et al*. (2023), who observed a significant ($p < 0.05$) link between rainfall intensity and microbial contamination in well water samples.

In Senegal, Pouye *et al*. (2023) discovered that frequent rain can transport contaminants over greater distances than typically expected, undermining recommended safety distances for well placement. This observation defines the findings of this study, where wells located distance from sanitation facilities still exhibited significant contamination possibly due to structural deficiencies identified in Aflao, such as the lack of concrete floors, the absence of cover and wells under trees. Therefore, well design and maintenance are important in controlling contamination (Jenifer and Jha, 2022). Furthermore, Olalemi, (2021) study in Nigeria found that the absence of *Salmonella* and *Shigella* in well water, despite the presence of *E. coli*, could be attributed to differences in contamination sources, microbial communities, or environmental conditions. This aligns with our study as indicated oganisms (*Salmonella* and *Shigella)* were absent in analysed well water samples *(Table 4)*.

An observation pertained to the deployment of standard well lining and parapet walls at all sample points, functioning as an effective barrier mechanism that delineated a protective interface between HDW water and potential contaminants originating from surface runoff (Okoye *et al*., 2023). Furthermore, this observation holds significance in the context of environmental hygiene, particularly given that the majority of these wells were typically situated within household premises and most houses owned a well which might reduce the risk of contamination from neighbours (Othoo *et al*., 2023).

The hydrogeological context has a key impact on the low detection limits of HMs recorded in the HDWs (Hao *et al*., 2024). Hydrogeological environments including recent and tertiary formations characterized by unconsolidated sands and clays, marine sands, and partially consolidated red continental deposits affect the prevalence of HMs in well water. These have significant adsorption capabilities for heavy metals, allowing them to retain metals in the soil and diminish their concentrations in groundwater (Bai *et al*., 2024). Coastal and riverine deposits influence groundwater recharge rates (Chmielarski *et al*., 2024). High recharge rates in river valleys and coastal regions can contribute to the diffusion of contaminants, contributing to reduced concentrations of HMs in the wells (Birla *et al*., 2020).

In some cases, HM contamination tends to come from natural mineral deposits located in deeper geological layers (Liu *et al*., 2024). Metals like As, Pb, and Cd may come from mineral-rich bedrock, but since HDWs do not reach these deep layers, they are less likely to locate water that has been in contact with such minerals (Richard *et al*., 2024). Groundwater flow through loosely consolidated sands and clays tends to be slower, allowing for higher contact with the soil matrix and enhanced possibility for metal attenuation (Wang *et al*., 2021). Additionally, the passage through marine clays and sands may promote the natural dilution of contaminants, resulting in lower detectable levels (Rahman *et al*., 2013).

The presence of industrial or anthropogenic activities near the wells or other water sources adds to HMs contamination through storm runoff and also geological features are identified as contributors to low HMs levels, with regions naturally low in metal concentrations yielding water with minimal contamination (Kapoor and Singh, 2021). Therefore, the absence of industrial activity could be a potential factor in the low detection limit of targeted HMs in the samples result of the recent study.

CONCLUSION

This study assessed the risk of HDW water in Aflao. The results discovered that all 20 wells tested were contaminated with total coliform (mean=579.7.00 CFU/100ml), and *E.coli* (14.7 CFU/100ml), and 18 wells contained faecal coliform (mean=32.6 CFU/100ml) and *E. coli* (mean=14.7 CFU/100ml), making the water unsafe for consumption by WHO standards (0 cfu/100ml). Although heavy metals (Pb, Cd, Cr, Ni, and As) were below minimum detection limits (0.001–0.01 mg/L), there was a strong association ($p<0.05$) between sanitary risk factors such as proximity to latrines, lack of concrete floors and covers, poor drainage, trees near wells, and shallow depth and microbial contamination. These findings recommend the need for better sanitation, replacement of components of the wells, education and promotion of well water treatment and hygiene to reduce contamination risks and safeguard public health in Aflao.

Limitations of the study

The findings are limited to the few numbers of purposively selected hand-dug well water samples which could be only indicative of samples taken given the potential biases with purposive sampling although selection criteria were defined. Also, seasonal variations (wet/rainy and dry) were not considered in the study design.

ETHICAL CONSIDERATION

The study received ethical approval from the Committee on Human Research, Publication, and Ethics at Kwame Nkrumah University of Science and Technology (CHRPE) with reference number “CHRPE/AP/569/23”. Informed consent was also obtained from the Ketu-South Municipal Assembly and all participants according to the directives of CHRPE.

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CONFLICT OF INTERESTS

The authors declare that there are no conflicts of interest.

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