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Physicochemical parameters and heavy metal concentrations in hand-dug well in Ga East municipality in southern Ghana

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Hand-dug wells play a crucial role as a primary source of drinking water for numerous communities, especially those lacking access to treated water. However, water from such wells can occasionally be contaminated, posing health risks. The purpose of the study was to investigate the physicochemical properties and heavy metal concentrations in thirty hand-dug wells in the Ga East Municipality of Ghana. Water samples from three communities underwent analysis at the Ghana Atomic Energy Commission. The results revealed that pH, temperature, phosphate, nitrate, sulfate, calcium, and salinity levels adhered to the World Health Organization's recommended guidelines. Additionally, all heavy metal concentrations remained within WHO standards.

Key words: Hand dug, physiochemical, metals, parameters, wells

INTRODUCTION

Access to clean high-quality water is crucial for preventing diseases and improving overall quality of life, aligning with Goal 6 of the Sustainable Development Goals (SDGs). Water quality is fundamental to human well-being, serving essential roles in domestic, agricultural, and industrial contexts (Patil et al., 2012). Groundwater, a significant global drinking water source, typically maintains good quality (Ayodele and Aturamu, 2011). However, concerns arise due to groundwater contamination from various human activities such as landfilling, septic tanks, agricultural chemical leaching, and natural pollutants (Adekunle, 2008; Amoako et al., 2011).

In Ghana, urban areas primarily rely on treated surface water for drinking, while rural communities traditionally use untreated surface water from natural sources, leading to widespread waterborne diseases (Nii Consult, 1998). Although groundwater is perceived as a safer option, recent studies highlight its vulnerability to contamination from both anthropogenic and natural sources (Nii Consult, 1998). This challenge is exacerbated by rapid population growth in places like Accra, where limited access to piped water has driven people to rely on hand-dug wells, often located near septic tanks due to space constraints (Duodu, 2014; Nyarko, 2008). This practice raises concerns about water

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contamination and associated health risks. Given these challenges, particularly in regions lacking access to treated water, there is an urgent need for comprehensive water quality assessments to protect public health (IDLO, 2006; WHO, 2006). Few studies have examined the temporal variability of water quality in hand-dug wells across different seasons or years in the Ga East municipality.

Understanding how physicochemical parameters and heavy metal concentrations evolve over time is crucial for effective water management and policy formulation. This research contributes to the theoretical understanding of the specific hydrochemical profile of hand-dug wells in the Ga East municipality. By identifying unique physicochemical parameters and heavy metal concentrations and providing a baseline characterization, this study enables comparative studies in similar regions. The findings will contribute to the development of theoretical frameworks for regulatory standards and policies aimed at safeguarding groundwater quality. By comparing observed contamination levels with national and international standards, the study offers theoretical insights into the adequacy of existing regulations and suggests areas for improvement. The research aims to address existing research gaps by assessing physicochemical parameters and heavy metal concentrations in water samples from hand-dug wells in the study area. This evaluation will serve to compare findings against the minimum standards set by the World Health Organization (WHO) and the Ghana Standards Authority (GSA), providing valuable insights into water safety and quality in the study area. Through this research, we aim to contribute new knowledge that can inform effective interventions to ensure safe and reliable water sources for communities reliant on hand-dug wells for domestic and drinking water needs.

Study areas

The study was carried out in the Agbogba and Dome communities in the Ga-East district of the Greater Accra region. Ga East Municipality is one of the 16 municipalities in the Greater Accra Region, located between latitudes 5°36' and 5°47'N and longitudes 0°15' and 0°11'W. It covers an area of 96 km and is bordered by the Ga West Municipality to the west, La Nkwantanang, and Madina Municipality to the east, and shares borders with the Akuapem South District to the north and Ayawaso West Municipality to the south. The capital of the Municipality is Abokobi, which is divided into two administrative zonal councils: Abokobi and Dome zonal. The municipality is situated in the coastal savannah agroecological zone and is characterized by shrub and grassland vegetation. The topography features gentle slopes, with the Akuapem range rising steeply at the western end, reaching heights between 37 and 420 m north of Aburi, and descending to 300 m southward. Rainfall is bimodal, with the major rainy season occurring between April and June, and a minor season from September to November. The average annual temperature ranges from 25.1°C in August to 28.4°C from February to March, with March being the hottest month and August the coldest. The primary economic activities in the municipality include agriculture, industry, services, and commerce (GSS, 2014).

Collection of water samples

Water samples were collected from private hand-dug wells in the Agbogba, Dome, and Madina communities using a convenience sampling method between October and November 2023. The samples were collected in clean, pre-sterilized, and properly labeled plastic containers measuring 500 ml, intended for the analysis of physicochemical properties and heavy metal parameters. Ten samples were collected from each community, for a total of 30 samples. Sampling took place between 7 am and 10 am, and the samples were tightly sealed in containers and transported to the laboratory. Upon arrival, samples were stored in desiccators before analysis

METHODS

Parameters such as pH, temperature, electrical conductivity (EC), and total dissolved solids (TDS) were measured on-site using portable instruments. All samples were transported to the laboratory within 24 hours of collection for further analysis. Various physicochemical parameters including turbidity, alkalinity, hardness, calcium (Ca), magnesium (Mg), sulfate, and nitrate were analyzed following the procedures outlined in the American Public Health Association (APHA, 2005) guidelines. Chromium (Cr), zinc (Zn), arsenic (As), cadmium (Cd), and lead (Pb) were quantified using an Atomic Absorption Spectrophotometer (Software AA300). All experiments were conducted in triplicate to ensure the reliability and consistency of the analyses.

Statistical analysis

Physiochemical parameters are expressed as mean ± standard deviation. Spearman’s rho correlation coefficient (r) matrices were used to analyze the heavy metals and p-value (significance level) of the statistics carried out. The mean was subjected to a one-way analysis of variance (ANOVA). The mean generated was subjected to a one-way analysis of variance (ANOVA). The Shapiro-Wilk test (Crawley, 2007) was used to assess the normality and homogeneity of variance. When the test indicated a significant difference, the means were compared using the post-hoc Tukey HSD test. The analysis was conducted using the R software version 4.1.1. The correlation between some physiochemical parameters such as pH, conductivity, chloride, total hardness, total dissolved solids, temperature, nitrate, phosphate, salinity, and other heavy metals (Fe, Zn, Cr, and Mn) was statistically analyzed using Spearman’s rho correlation coefficient (r) matrix. Data on correlation analysis was conducted with the statistical Programmed for Social Sciences (SPSS) version 20

Table 1. Mean values and standard deviations of physiochemical parameters compared to WHO standards.

Parameters	Locations						WHO standards	Statistically significant difference
	Agbogba		Dome		Madina			
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation		
pH	7.46	0.11	7.90	0.15	7.63	0.15	6.5-8.5	P > 0.05
Conductivity (µs/cm)	855.4	89.17	1548.7	126.10	936.8	126.10	1000	P < 0.001
Total alkalinity (mg/L)	674.4	136.1	966.0	192.4	530.2	192.4	120	P > 0.05
Temperature (°C)	30.53	0.61	30.20	0.86	30.89	0.86	30.5	P > 0.05
Total dissolved solid (mg/L)	427.9	49.07	767.6	69.40	520.2	69.40	500	P < 0.001
Total hardness (mg/L)	154.8	23.54	322.0	33.29	118.3	33.29	100	P < 0.001
Phosphate (mg/L)	0.16	0.04	0.12	0.06	0.17	0.06	5	P > 0.05
Nitrate (mg/L)	0.67	0.15	0.71	0.22	0.68	0.22	50	P > 0.05
Sulphate (mg/L)	12.09	2.77	17.37	3.92	14.68	3.92	250	P > 0.05
Calcium (mg/L)	37.6	6.08	55.20	8.60	47.46	8.60	75	P > 0.05
Chloride (mg/L)	153.4	18.59	464.86	26.29	250.83	26.29	250	P < 0.001
Potassium (mg/L)	20.03	3.82	20.50	5.41	20.44	5.41	5	P > 0.05
Sodium (mg/L)	194.09	17.64	303.70	24.95	208.14	24.95	250	P < 0.001
Magnesium (mg/L)	1.08	0.09	0.87	0.13	0.61	0.13	30	P < 0.001
Salinity (%)	0.28	0.04	0.32	0.06	0.32	0.06	0.5	P > 0.05

RESULTS

Physiochemical parameters

Table 1 presents the findings concerning the physiochemical parameters of hand-dug wells in Ga East Municipality. The mean pH across various locations ranged from 7.5 ± 0.1 to 7.9 ± 0.2, showing no significant difference ($p > 0.05$) and falling within the World Health Organization's standards for drinking water. Mean conductivity was highest in the Dome community (1548.7 ± 126.1) and lowest in Agbogba (855.4 ± 89.2), with significant variation among locations ($P < 0.001$), although Dome's values did not meet WHO standards. Total alkalinity was highest in Agbogba (966.0 ± 192.4) and lowest in Madina (530.2 ± 192.4), with no significant difference among locations ($P < 0.05$), all failing to meet the WHO standards. Mean salinity was highest in Dome (0.32 ± 0.06) and lowest in Agbogba (0.28 ± 0.04), meeting WHO standards without significant differences among locations ($P > 0.05$). The mean temperature was higher in Madina (30.89 ± 0.86) and lower in Agbogba (30.53 ± 0.61), with no significant differences among locations ($P > 0.05$), except for Dome, where values slightly exceeded WHO standards for drinking water.

Total dissolved solids were higher in Dome (767.6 ± 69.40) and lower in Agbogba (427.9 ± 49.07), with significant variation among locations ($P < 0.001$). Except for Agbogba, Madina and Dome communities did not meet the WHO standards. The total hardness was highest in Dome (322.0 ± 33.3) and lowest in Madina (118.3 ± 33.3), showing significance ($P < 0.001$). Mean nitrate values were observed to be higher in Dome (0.71 ± 0.22) and lower in Agbogba (0.67 ± 0.15), with no significance ($P > 0.05$), within WHO standards. Phosphate values were higher in Madina (0.17 ± 0.06) and lower in Dome (0.12 ± 0.04). The mean sulfate value was higher in Dome (17.4 ± 3.9) and lower in Agbogba (12.1 ± 2.8), with no significance ($P > 0.05$), meeting WHO standards. Mean calcium was higher in Dome (55.2 ± 8.6) and lower in Agbogba (37.6 ± 6.1), with no difference across locations. Mean potassium was higher in Dome (20.50 ± 5.4) and lower in Agbogba (20.0 ± 3.8). Mean chloride values were higher in Dome (464.9 ± 26.3) and lower in Agbogba (153.4 ± 18.6), with significant variation among locations ($P < 0.001$).

Heavy metals concentrations in hand-dug well

Table 2 shows the concentrations of heavy metals in hand-dug wells across various locations. The findings revealed that the mean lead (Pb) concentration was consistent (< 0.001 x 10-3) across locations and within acceptable levels. Similarly, the mean copper (Cu) concentration (< 0.003 x 10-3) was uniform across the study areas. However, iron (Fe) levels were notably higher (0.37 ± 0.10) in the Madina community and lower (0.12 ± 0.07) in the Dome community, with significant variation among locations ($P < 0.05$). Zinc concentrations were elevated (0.056 ± 0.083) in Dome and lower (0.262 ± 0.059) in Madina, with a significant difference observed among the locations ($P < 0.05$). Chromium concentrations were higher (0.017 ± 0.002) in Dome and Agbogba, but

Table 2. Mean values and standard deviations of heavy metals concentrations compared to WHO standards.

Parameters	Locations						WHO values	Statistically significant difference
	Agbogba		Dome		Madina			
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation		
Pb	< 0.001	10^{-3}	< 0.001	10^{-3}	< 0.001	10^{-3}	0.01	P > 0.05
Cu	< 0.003	10^{-2}	< 0.003	10^{-2}	< 0.003	10^{-2}	2	P > 0.05
Fe	0.132	0.10	0.12	0.07	0.37	0.10	1.0	P < 0.05
Zn	0.29	0.06	0.56	0.08	0.26	0.05	5	P < 0.05
Cr	0.017	0.002	0.017	0.002	0.16	0.001	0.05	P > 0.05
Cd	< 0.002	10^{-2}	< 0.002	10^{-2}	< 0.002	10^{-2}	0.002	P > 0.05
Mn	0.018	0.002	0.011	0.001	0.015	0.002	0.05	P > 0.05
Ni	< 0.001	10^{-3}	< 0.001	10^{-3}	< 0.001	10^{-3}	0.01	P > 0.05

lower (0.016 ± 0.001) in Madina, with no significant variation among locations (P > 0.05). Cadmium (Cd) concentrations (< 0.002 x 10-3) were consistent across locations and were within acceptable limits. Mn levels were higher (0.018 ± 0.002) in Agbogba and lower (0.011 ± 0.001) in Dome, remaining within acceptable limits. Ni concentrations (< 0.001 x 10-3) were similar across all locations.

Correlation analysis of physicochemical parameters and heavy metals

Table 3 presents the results of the correlation analysis of the physiochemical parameters. The findings indicated a significant positive correlation between pH and conductivity (r = 0.45, p < 0.05) and a significant negative correlation between pH and phosphate (r = -0.21, p < 0.01) at a 99% confidence level. Similarly, conductivity showed significant positive correlations with total hardness (r = 0.51, p < 0.01) and calcium (r = 0.458, p < 0.001) at the 99% confidence level. The total hardness was positively correlated with chloride (r = 0.506, p < 0.01), nitrate (r = 0.480, p < 0.001), and salinity (r = 0.456, p < 0.001). Additionally, the total dissolved solids were significantly positively correlated with calcium (r = 0.716, p < 0.001) and nitrate (r = 0.480, p < 0.001). Chloride was significantly positively correlated with the total hardness (r = 0.602, p < 0.001) and salinity (r = 0.484, p < 0.001). Nitrate was significantly positively correlated with the total dissolved solids (r = 0.480, p < 0.01). Furthermore, sulfate showed a significant positive correlation with nitrate (r = 0.407, p < 0.05) and a significant negative correlation with phosphate (r = -0.503, p < 0.001) at a 95% confidence level. Salinity was significantly positively correlated with total dissolved solids (r = 0.363, p < 0.05) and nitrate (r = 0.449, p < 0.05) and negatively correlated with phosphate (r = -0.503, p < 0.05) at a 95% confidence level.

Table 4 presents the results of the correlation analysis for the heavy metals. Iron exhibits a strong positive correlation with Cr (r = 0.172) at a significance level of 99%, as well as with Mn (r = 0.338), but it shows a negative correlation with Zn (r = -0.67) at a significance level of 95%. Zn was positively correlated with Cr (r = 0.155) and negatively correlated with Mn (r = -0.232) at a confidence level of 95%. Furthermore, Cr was positively correlated with Fe (r = 0.172), Zn (r = 0.293), and Mn (r = 0.293).

DISCUSSION

Physiochemical parameters of water samples

The pH of the water fell within the acceptable range for drinking water according to the World Health Organization (2004), which is 6.5–8.5, indicating alkaline properties, consistent with observations by Isah et al. (2015). This suggests that the water is suitable for various purposes such as agriculture, recreation, and household use. However, conductivity levels exceeded the WHO limit for drinking water of 1000 mg/L, contradicting values documented by Onu (2024) but aligning with findings from Addo et al. (2023). Water conductivity measures its ability to conduct electrical flow and depends on the concentration of conductive ions present, typically from inorganic materials like chlorides, alkalis, carbonates, sulfides, and dissolved salts.

The study also found that water temperature remained within WHO permissible limits, except for the Madina community, which showed slightly elevated temperatures beyond the recommended threshold. Total dissolved solids were below acceptable levels for drinking water in the Agbogba community but exceeded the recommended 500 mg/L in the Dome and Madina communities. High total dissolved solids can lead to excessive scaling in water pipes, as noted by WHO (2006), and according to

Table 3. Spearman's rho correlation matrix for physiochemical parameters.

Variable	pH	Conductivity	Temp	Total hardness	TDS	Ca	Cl	N	P	SO_4	Salinity
pH	1.000	0.458*				0.615*	0.372*		-0.21		
Conductivity		1.00		0.51**		0.404*					
Temp			1.000		-0.363*	-0.002	- 0.275				
Total hardness				1.000			0.506 **	0.480**			0.458 **
TDS					1.000	0.716**		0.480 **			
Ca						1.000		0.420**			
Cl							1.000				0.484**
N								1.000			
P									1.000		-0.503**
SO_4										1.000	
Salinity											1.000

*and ** correlation is significant at the 0.05 and 0.01 levels (2-tailed) respectively.

Table 4. Spearman's rho correlation matrix for heavy metal concentration.

Variable	Fe	Zn	Cr	Mn
Fe	1.000	-0.67	0.172	0.338
Zn		1.000	0.155	-0.232
Cr	0.172	0.293	1.000	0.293
Mn				1.000

*and ** correlation is significant at the 0.05 and 0.01 levels (2-tailed) respectively.

Apau et al. (2014), they can make water unpalatable for human consumption. Furthermore, the total hardness values recorded in water samples from various locations surpassed the permitted safety limit for drinking water from hand-dug wells. This high total hardness may result from the leaching of dissolved calcium and magnesium into the wells, potentially leading to hard scales and rust on cooking utensils and other metal objects when heated. This observation is consistent with reports by Isah et al. (2015), who noted higher total hardness in hand-dug wells.

Additionally, the study revealed that the concentrations of magnesium, calcium, nitrate, phosphates, and sulfate were below WHO permissible limits for drinking water, in agreement with previous findings by Onu (2024) and Isah et al. (2015), who reported low values of these elements in hand-dug wells. However, potassium levels exceeded the acceptable WHO guidelines for drinking water. Finally, the salinity level in the water remained within WHO permissible limits, consistent with findings by Onu (2024).

Heavy metal concentrations of water samples

The levels of copper detected in water at all sampling points were found to be below the WHO permissible limit of 2 µg/l. This finding contrasts with the results of Gyamfi et al. (2012), who reported higher copper values ranging from 3 to 308 μg/l than those found in this study, which also remained below the guideline values. Regarding lead (Pb), the concentrations in samples from various locations were below the World Health Organization's permissible standard for drinking water, set at 0.01 mg/L This finding is not consistent with the findings of Amankwa et al. (2023) in the Wa municipality of Ghana. Additionally, the concentrations of nickel (Ni), iron (Fe), zinc (Zn), cadmium (Cd), and chromium (Cr) in the various samples were all below the WHO permissible standard for drinking water. Hence, based on heavy metal concentrations, the water qualities from the different sample locations are deemed safe for drinking. Similar findings have been documented by Amfo-Oto and Omari (2012), who observed that the concentrations of iron and manganese in water were below the permissible limits set by the World Health Organization.

Conclusion

In conclusion, the physicochemical parameters and concentrations of heavy metals in the dugout wells suggest that the water is generally safe for drinking. However, certain parameters such as conductivity, total alkalinity, total dissolved solids, chloride, and sodium levels exceeded the acceptable limits established by the World Health Organization. Despite these exceedances, all other parameters remained within permissible limits, and none of the heavy metal concentrations surpassed the recommended standards set by the WHO. Therefore, while some aspects of water quality require attention and remediation, overall, the water from these dugout wells can still be considered safe for consumption with appropriate treatment or monitoring of the aforementioned parameters. These findings highlight the importance of an integrated approach to water management that considers public health, environmental sustainability, economic viability, and social well-being.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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