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Research article

Heavy metal concentrations in drinking water sources in two mining districts in Ghana

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A B S T R A C T

- In Ghana, mining of minerals at small-scale and large-scale is widespread across many districts, leading to significant heavy metal pollution in the environment. In this study, the concentrations of iron (Fe), manganese (Mn), arsenic (As), and mercury (Hg) in the different drinking water samples collected from households, institutions, water points and surface water in two mining districts namely the Wassa East and Asutifi North were analyzed. The water types collected included boreholes, wells, piped water into yards, public standpipes, rainwater, sachet water, and surface water. The results indicated that the levels of Fe and Mn were higher than As and Hg in all the drinking water samples. The levels of As and Hg in drinking water from households and institutions were higher in the Wassa East district compared to the Asutifi North district. However, the metal levels at water points were similar in both districts. In surface water, Fe levels were higher in the Wassa East district compared to the Asutifi North district with median values of 1243 μg/L and 860 μg/L for the Wassa East and Asutifi North districts, respectively. In contrast, the Mn levels were higher in the Asutifi North district than the Wassa East district with median values of 9.5 μg/L and 90 μg/L for Wassa East and Asutifi North districts, respectively. All the metals (Mn, As, and Hg) studied except Fe were within the recommended WHO level. The Heavy Metal Pollution Index (HPI) values for the different water types in households, institutions and water points were all below the critical limit of 100. The Water Quality Index (WQI) indicates that the boreholes, piped water into yards, and public standpipes in both districts were classified as excellent or good, making them suitable for drinking. However, the wells and surface water in both districts were classified as very poor and unfit for drinking, respectively.

1. Introduction

Water is an important resource required by all living organisms. Humans utilize water for various domestic, agricultural, and industrial purposes [1–3]. The quality of water depends on its physical, chemical, and biological properties [4–6]. Water quality is affected by both natural and anthropogenic factors [6,7]. The natural factors include the types of rocks, weathering, volcanic activities and chemical interactions of the water and rocks within the watershed [7–12]. Anthropogenic activities such as mining, domestic, agricultural, and industrial waste also contribute to water quality degradation [6,9–11,13–15]. These anthropogenic activities release various types of pollutants including heavy metals into the water, rendering it unsuitable for drinking.

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Heavy metal pollution of water resources has been reported worldwide [3,16–20]. Heavy metals have been detected in water resources, such as surface water and groundwater [10,19,21]. Some heavy metals serve as essential nutrients and are required by organisms at low concentrations. However, when the concentrations exceed the threshold levels, they become toxic to organisms [12]. Exposure to heavy metals in water can lead to various toxic effects, such as cancer, DNA damage, neurotoxic effects, kidney failure, and accumulation in different tissues [17,21].

In Ghana, mining minerals is widespread, leading to significant heavy metal pollution [9,10,20,22]. This pollution is exacerbated by inadequate monitoring and assessment of mining's impact on water bodies. Since the 1980s, the Government of Ghana has initiated intervention programs to minimize the impact of mining on the environment [23].

Mining in Ghana occurs on both small and large scales. Small-scale mining, involving Hg amalgamation and using basic equipment, is typically done by indigenous people [10,22,24], while large-scale mining is undertaken by established companies [25]. Despite providing employment, mining negatively affects the environment through deforestation, air pollution, and water pollution from dredging, releasing heavy metals into water bodies [22]. The environmental consequences, especially heavy metal pollution and increased water turbidity from small-scale mining, are severe. Nevertheless, small-scale mining persists in Ghana, leading to significant water pollution in affected communities.

Numerous studies have examined the impact of mining on water quality in Ghana [5,9,10,20,26]. Despite people in mining communities using water for domestic purposes, including drinking, there has been limited attention given to a detailed comparison of the quality of drinking water in households, institutions and water points. These are specific locations or environments where different water types are collected for drinking and other purposes. The households consist of a house and its occupants; the institutions include schools and hospitals; and the water points are areas with a specific water source where the general public collects water. This study evaluated water quality by analyzing heavy metal levels in drinking water sources used in households, institutions and water points in two mining districts. Various types of water (treated water, groundwater, and surface water) used for drinking in households, institutions, and water points were analyzed for heavy metals. Additionally, different pollution indices were used to assess water quality.

Different pollution indices, such as the Heavy Metal Pollution Index (HPI), Heavy Metal Evaluation Index (HEI), and Water Quality Index (WQI), are used to assess water quality [1,2,12,27,28]. This study utilized the HPI and WQI to evaluate water quality. The HPI assessed the cumulative effect of heavy metals on water quality, while the WQI allowed for the selection of various parameters to evaluate water quality comprehensively. Both indices have been widely used in water quality assessments [1,2,5,7,28].

In the present study, the objectives are: 1) to determine heavy metal concentrations (Fe, Mn, As, and Hg) in drinking water sources in households, institutions and water points in two mining districts in Ghana; 2) to determine heavy metal levels in different water types in these districts; 3) to compare heavy metal concentrations in water samples from the two districts; 4) to compare heavy metal concentrations in drinking water with WHO recommended levels; 5) to assess water quality using the Heavy Metal Pollution Index (HPI) and the Water Quality Index (WQI).

2. Materials and methods

2.1. Study area

The study was carried out in the Wassa East District in the Western Region and the Asutifi North District in the Ahafo region of Ghana (Fig. 1). These two districts are known for both small-scale and large-scale gold mining. The Asutifi North district is located in the Ahafo Region of Ghana, and the capital is Kenyasi. The district covers an area of 1500 km^2 [25] and has elevation ranging from 200 to 467 m above sea level. The vegetation consists of moist semi-deciduous forest and falls within an area that has two seasons namely the wet and dry seasons. The main river basin that drains this district is the River Tano and its streams; which run through many towns in the district. The yearly rainfall varies between 1400 and 1750 mm. The rocks are mainly Birimian and contain a lot of gold and other mineral deposits [29,30]. This has led to increased mining activities in the district, contributing to the pollution of water resources.

Wassa East district is located in the Western region of Ghana and the capital is Daboase. It covers an area of 1651.992 km^2, and it is mostly rural [20]. The district has many areas below 150 m sea level, and the highest areas are between 150 and 200 m above sea level. The main river basin that drains this district is the river Pra and its tributaries. The vegetation is tropical rainforest and is characterized by two seasons (wet and dry season). The mean annual rainfall is 1500 mm. The rocks and soils are described as lower Birimian, Tarkwanian and Cape Coast granite rocks and soils. There are large mineral deposits in these rocks, leading to an increase in mining activities. The mining activities have contributed to the contamination of the water resources in this district [31].

Both districts are rural, with over 80 % and 92 % of the inhabitants respectively, living in the rural areas of Asutifi North and Wassa East districts, compared to the national average of 49 %. Also, Asutifi North District has a crude death rate of 8.8 per 1000 compared to 11.4 per 1000 in Wassa east. In the Asutifi North District, 56.8 % of the populations above 15 years old are into farming, while 8.0 % are into mining and quarrying. In contrast, 71.2 % of the population over 15 years old in the Wassa East District are into farming, compared to 3.7 % who are into mining and quarrying [30,31]. As a result of increasing mining activities in these districts, farming activities are reducing as farmers rent their lands to large-scale mining companies for various compensations. This appears to be much more pronounced in Asutifi North compared to Wassa East, as the population involved in mining in Asutifi North is higher than in Wassa East. The population involved in farming is higher in Wassa East than in Asutifi North. Some of the large-scale mining companies are Newmont Ghana Gold Limited in Asutifi North district and Gold Star Resources in Wassa East district [25,32].

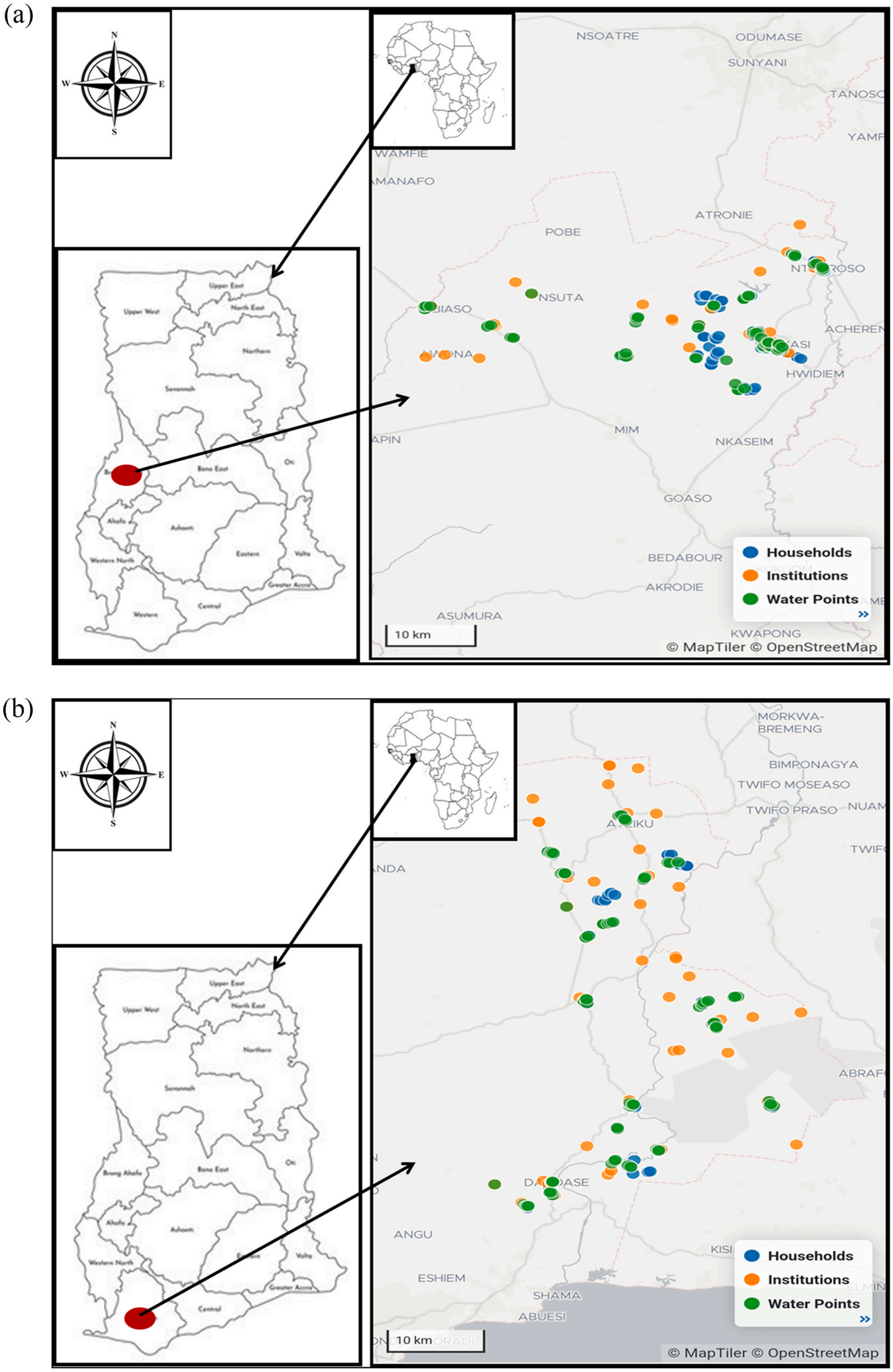

Fig. 1. Map of sampling points where the drinking water was collected. These include households, institutions and water points in (a) the Asutifi North district and (b) the Wassa East district of Ghana.

2.2. Sample collection

The samples were collected from 36 different communities within the Asutifi North and Wassa East districts in Ghana. The samples were collected in November and December 2022 by trained water quality fellows (students) after a week of intensive training. The water samples were collected from boreholes (borehole with hand pump and mechanized borehole), wells (protected and unprotected dug wells), public standpipes, piped water into yard, sachet water, rainwater and surface water. The water samples were collected from households, institutions and water points. In addition, surface water that was not designated as water points was also collected from these districts. The pH, temperature, turbidity and conductivity of all water types (except rainwater and sachet water) were measured during sample collection (Table 1). The total samples collected from both districts were 808, 256, 797 and 172 for households, institutions (schools and hospitals), water points and surface water respectively. A subsample was analyzed for heavy metals. However, all the surface water samples were analyzed. This is shown in Tables 2 and 3. The water that flowed through pipes and pumps were allowed to flow for 3 min before it was collected [4,28]. The water samples were collected in acid washed plastic containers. These plastic bottles were washed with 10 % nitric acid [1,5]. The water samples collected were acidified by adding three drops of concentrated nitric acid. This was to keep metals in solution and prevent precipitation and binding of metals to the walls of containers [1,7,33,34]. The samples were then transported to the laboratory for analysis. A brief survey was also carried out using the mWater app (https://portal.mwater.co/#/) on household characteristics, water types and accessibility to water.

2.3. Water analysis

The Fe, Mn, Hg and As were analyzed with Atomic Absorption Spectrophotometer (PerkinElmer PinAAcle 900T). The physico-chemical parameters of the different water types were measured with the Hach, Pocket Pro + Tester, Hach, 2100Q Portable Turbidity Meter and the Horiba U-50 multiparameter water quality meter. The temperature, conductivity and pH of water samples collected from households, institutions and water points were measured with the Hach Pocket Pro + Tester. The Hach 2100Q Portable Turbidity Meter was used to measure the turbidity of the water samples. For surface water that did not serve as water points, the temperature, conductivity, pH and turbidity were measured with the Horiba U-50 multiparameter water quality meter.

2.3.1. Assessment of water quality using heavy metal pollution index (HPI)

The Heavy Metal Pollution Index (HPI) was used to assess the heavy metal pollution in water sources. The (HPI) is a numerical value that is the combined effect of the heavy metals on water quality [1,5,28]. Values less than 100 indicate that the water is suitable for human consumption, and values greater than 100 indicate that the water is polluted and not suitable for consumption. The HPI is calculated using the following equations:

$$HPI = \frac{\sum_{i=1}^{i=n} Wi \times Qi}{\sum_{i=1}^{i=n} Wi} \quad (1)$$

The Q_i is the subindex of the ith parameter, W_i is the unit weight of the ith parameter, and n is the number of parameters considered; the subindex (Q_i) of the parameter is

$$Qi = \frac{Vi}{Si} \times 100 \quad (2)$$

The Vi is mean value of the metals and the Si is the standard value. In the present study we used the WHO standard value.

2.3.2. Assessment of water quality using the water quality index (WQI)

The water quality index (WQI) is a numerical value that is used to assess the quality of water resources. In the present study, we

Table 1
Physico-chemical parameters of the different water types from the Wassa East district and Asutifi North district in Ghana. The values shown are the mean and standard deviations.

Districts	Water type	pH	Conductivity (µS/cm)	Temperature (°C)	Turbidity (NTU)
Wassa East	Borehole	6.08 ± 0.70	254.49 ± 143.19	28.98 ± 1.74	2.45 ± 7.10
	Piped water into yard	6.53 ± 0.72	319.66 ± 374.37	30.37 ± 2.15	2.863 ± 4.13
	Public stand pipe	5.62 ± 1.16	221.53 ± 162.59	29.92 ± 2.05	1.36 ± 1.70
	Surface water	6.72 ± 0.32	123.92 ± 121.26	27.29 ± 1.42	27.99 ± 28.61
	Well	5.61 ± 0.51	308.17 ± 221.03	29.34 ± 1.09	9.14 ± 18.83
Asutifi North	Borehole	5.85 ± 0.72	217.63 ± 189.07	28.95 ± 1.99	1.48 ± 3.12
	Piped water into yard	6.3 ± 0.32	189 ± 46.78	29.77 ± 2.04	0.32 ± 0.028
	Public stand pipe	6.51 ± 0.62	233.21 ± 108.62	32.05 ± 3.11	1.40 ± 2.12
	Surface water	6.4 ± 0.71	122.75 ± 41.87	28 ± 2.96	15.60 ± 13.52
	Well	6.06 ± 0.67	485.23 ± 461.53	28.55 ± 1.47	10.32 ± 18.05
WHO limits		6.5–8.5	1000		5

Table 2
Comparison of heavy metal concentrations (μg/L) at households, institutions and water points in the Wassa East district and Asutifi North district. The values shown are the median and IQR (interquartile range). The analysis is a *Kruskal-Wallis* test (medians with similar letters are statistically not different).

Districts	Water type	N	As	*IQR*	Fe	*IQR*	Hg	*IQR*	Mn	*IQR*
Wassa East	Household	177	0.19 a	0.11	21 a	90	0.14 a	0.1	4 a	11
	Institution	20	0.25 a	0.0625	21.5 a	21.25	0.205 a	0.065	7.5 a	8.75
	Water point	100	0.19 a	0.1325	32 a	112.25	0.14 a	0.12	7.5 a	27
Asutifi North	Household	184	0.16 a	0.1	21 a	49	0.12 a	0.09	6 a,b	11
	Institution	35	0.13 b	0.025	7 a	57.5	0.1 b	0.03	2 a	5
	Water point	88	0.195 c	0.1025	25 a	41.25	0.155 c	0.09	10 b	16.25

Table 3
Comparison of heavy metal concentrations (μg/L) in the different water types collected from households, institutions and water points in Wassa East district and Asutifi North district. The values shown are the median and IQR (interquartile range). The analysis is a *Kruskal-Wallis* test (medians with similar letters are statistically not different).

Districts	water type	N	As	*IQR*	Fe	*IQR*	Hg	*IQR*	Mn	*IQR*
Wassa East	Borehole	104	0.2 a	0.1025	18 a	47.25	0.14 a	0.09	5.5 a	13
	Piped water into yard	5	0.18 a	0.06	28 a,b	90	0.12 a	0.04	8 a	8
	Public stand pipe	28	0.15 a	0.0525	3.5 a	75.75	0.12 a	0.04	1.5 a	7.25
	Rain water	10	0.18 a	0.1025	20 a	40.25	0.13 a	0.085	10 a	8.75
	Sachet water	22	0.185 a	0.095	20 a	31.5	0.14 a	0.0875	6 a	11.75
	Surface water	50	0.31 b	0.1675	508.5 b	768	0.24 b	0.12	11 a	28.75
	Well	56	0.18 a	0.12	20.5 a	41.5	0.14 a	0.1025	10 a	11.5
Asutifi North	Borehole	84	0.16 a	0.1	20 a	37	0.11 a	0.08	6 a	10.25
	Piped water into yard	7	0.14 a	0.08	41 a	50.5	0.11 a	0.05	4 a	6.5
	Public stand pipe	18	0.155 a	0.07	36.5 a	53.25	0.105 a	0.08	7 a	10.25
	Sachet water	9	0.14 a	0.02	21 a	34	0.11 a	0.05	5 a	3
	Surface water	2	0.195 a	0.095	46 a	44	0.12 a	0.08	15.5a	14.5
	Well	21	0.24 b	0.06	24 a	53	0.19 b	0.04	10 a	19

used the arithmetic weighted WQI method to quantify water quality. The selected parameters used in the present study were the pH, conductivity, turbidity, Fe, Mn, As and Hg of the water samples. A WQI <25, indicates excellent water; a WQI = 26–50, indicates good water; a WQI = 51–75, indicates poor water; a WQI = 76–100, indicates very poor water; a WQI >100, indicates water unsuitable for drinking. The WQI is calculated using the following equations:

$$\boldsymbol{WQI} = \frac{\sum_{i=1}^{i=n} \boldsymbol{Wi} \times \boldsymbol{Qi}}{\sum_{i=1}^{i=n} \boldsymbol{Wi}} \tag{1}$$

Where *Qi* is the quality rating of the ith parameter and *Wi* ($\sum Wi = 1$) is the unit weight of the ith parameter.

$$\boldsymbol{Qi} = \frac{\boldsymbol{Vi} - \boldsymbol{V0}}{\boldsymbol{Si} - \boldsymbol{v0}} \times \mathbf{100} \tag{2}$$

Vi is the concentration of the *ith* parameter, *V0* is the ideal value for conductivity and turbidity ($V0 = 0$), however, for pH ($V0 = 7$) and *Si* is the standard value of the ith parameter, In the present study we used the WHO standard value.

$$\mathrm{wi} = \frac{\boldsymbol{K}}{\boldsymbol{Si}} \tag{3}$$

$$\mathrm{K} = \frac{\mathbf{1}}{\sum \left(\frac{1}{Si} \right)} \tag{4}$$

K is the proportional constant.

2.4. Statistics analysis

The normality of the data were checked prior to analysis, and the homogeneity of variance was tested using Bartletts test. The data that were not normally distributed or homoscedatic were analyzed using a non-parametric test. The Kruskal–Wallis test was used to analyze the differences in Fe, Mn, As and Hg in water samples from households, institutions (schools and hospitals) and water points in both districts. The Kruskal–Wallis test was used to analyze the differences in Fe, Mn, As and Hg in the different water types in both districts. The Mann-Whitney *U* test were used to compare Fe, Mn, As and Hg levels between the two districts for surface water, households, institutions and the water points. All statistical analyses were conducted with R.

3. Results

3.1. Household characteristics, water types and accessibility to water

The percentage of respondents in Asutifi North and Wassa East Districts in households with a family size of more than five people is 52.33 %. Most (99.9 %) of the households have more than one room for sleeping, and 77 % of the respondents have a member of the household with agricultural land.

In these households, the main sources of drinking water were boreholes which include boreholes with hand pumps and mechanized boreholes (38.7 %), sachet water (12.1 %), public standpipes (11.8 %), well water including protected and unprotected dug wells (10.7 %), surface water (9.6 %), piped water into yard/plot (7.4 %), rainwater (2.2 %) and other water sources (7.6 %) which were not included in our analysis. The percentage of the respondents who had access to water within 30 min of their houses was (88 %). The percentage of the respondents who had had sufficient water within the month was (68 %).

3.2. Heavy metals levels in drinking water in households, institutions and water points

The heavy metal levels in drinking water in households, institutions (schools and hospitals) and water points in Asutifi North and Wassa East Districts are shown in Table 2. In the Asutifi North district drinking water samples collected from households, institutions and water points, the concentration of metals was in the order Fe > Mn > As > Hg. There was no significant difference for Fe in drinking water from households, institutions and waterpoints ($p > 0.05$). There was a significant difference for As, Mn and Hg levels in drinking water from households, institutions and water points ($p < 0.05$). The highest concentrations of these metals (As Mn and Hg) were recorded at the water points and the lowest were at the institutions. The Mn levels were not significantly different ($p > 0.05$) between water points and households and between households and institutions.

In the Wassa East district, the concentration of metals in the drinking water samples collected from households, institutions and waterpoints was in the order Fe > Mn > As > Hg. There was no significant difference for all the metals analyzed in the drinking water from households, institutions and waterpoints ($p > 0.05$).

3.3. Heavy metals levels in drinking water types

The heavy metal **levels** in the different water types collected are shown in Table 3. In the Asutifi North District, the concentration of metals in the different water types was in the order Fe > Mn > As > Hg. There was no significant difference for Fe and Mn for the different water types ($p > 0.05$). There was a significant difference in As and Hg levels between the different water types ($p < 0.05$). The As levels were significantly higher in well water than the other water types. The Hg levels in well water were significantly higher ($p < 0.05$) than the other water types. All the other water types did not show a significant difference ($p > 0.05$) in As and Hg levels.

In the Wassa East district, the concentration of metals in the different water types was in the order Fe > Mn > As > Hg. There was no significant difference in Mn levels for the different water types ($p > 0.05$). There was a significant difference in As Fe, and Hg levels between the different water types ($p < 0.05$). The As levels in surface water were significantly higher than all the other water types (Well water, rainwater, sachet water, piped water into yard, public standpipes and borehole water). All the other water types had

Table 4
Comparison of heavy metal concentrations (μg/L) between Wassa East district and Asutifi North district for surface water, households, institutions and water points. The surface water includes all the surface water in the districts and not only those used as water points. The values shown are the median and range.

Metal (ug/L)	Source of water	Wassa East	Asutifi-North	*Mann-Whitney test*
Hg	Household	0.14 (0.1–1.45)	0.12 (0.04–0.32)	W = 116, p = 0.0000
	Institution	0.21 (0.1–0.38)	0.1 (0.03–0.2)	W = 56, p = 0.0000
	Water point	0.14 (0.1–10.25)	0.155 (0.06–1.7)	W = 406, p = 0.357
	Surface water	0.32 (0.12–15.8)	0.4 (0.08–1.11)	W = 347, p = 0.7744
As	Household	0.19 (0.11–2.28)	0.16 (0.1–0.48)	W = 127, p = 0.0003
	Institution	0.25 (0.14–0.56)	0.13 (0.1–0.27)	W = 65.5, p = 0.0000
	Water point	0.19 (0.11–10.7)	0.195 (0.11–0.61)	W = 413, p = 0.460
	Surface water	0.40 (0.11–21.2)	0.46 (0.12–2.96)	W = 366, p = 0.365
Fe	Household	21 (Bd –2720)	21 (Bd - 1516)	W = 154, p = 0.372
	Institution	21.5 (2–71)	7 (Bd –608)	W = 268.5, p = 0.156
	Water point	32 (Bd - 11320)	25 (1–2640)	W = 419, p = 0.5637
	Surface water	1243 (1–52220)	860 (1–105800)	W = 226, p = 0.0003
Mn	Household	4 (Bd –190)	6 (Bd –150)	W = 177, p = 0.137
	Institution	7.5 (1- 41)	2 (1–158)	W = 223, p = 0.0248
	Water point	7.5 (1–244)	10 (1–202)	W = 461, p = 0.573
	Surface water	9.5 (Bd –661)	90 (1–1821)	W = 503, p = 0.0000

Table 5
Comparison of average metal concentrations (μg/L) in drinking water with WHO guidelines for drinking water. Surface water[a] is surface water collected from households, institutions and water points, while surface water[b] includes all the surface water in the districts (and not only those used as water points).

District	Metals (μg/L)	Household	Institution	Water point	Boreholes	Piped water into yard	Public stand pipe	Sachet water	Well	Surface water[a]	Surface water[b]	Rain water	WHO
Wassa East	Hg	0.2	0.21	0.3	0.185	0.154	0.142	0.22	0.194	0.501	0.78	0.166	6
Asutifi-North		0.14	0.1	0.18	0.153	0.119	0.132	0.13	0.179	0.12	0.42	–	
Wassa East	As	0.26	0.26	0.35	0.239	0.204	0.181	0.29	0.252	0.585	1.06	0.205	10
Asutifi-North		0.18	0.14	0.21	0.183	0.166	0.177	0.16	0.252	0.195	0.6	–	
Wassa East	Fe	163.42	28.35	**398.34**	93.48	63.8	55.82	45.6	103.66	**1061.04**	**4841.6**	102.9	300
Asutifi-North		51.3	47.79	114.36	36.95	99.29	50.67	46.1	113.67	46	**2967.3**	–	
Wassa East	Mn	15.47	10.1	23.51	16.02	8	11.29	17.2	15.89	34.2	69.53	7.6	400
Asutifi-North		13.72	13.23	19.6	13.93	5.57	17.33	6.44	17.95	15.5	183	–	

similar As levels. The Fe levels in surface water were significantly higher ($p < 0.05$) than all the other water types. All the other water types did not show a significant difference ($p > 0.05$) in Fe levels. The Hg levels in surface water were significantly higher ($p < 0.05$) than all the other water types. All the other water types did not show a significant difference ($p > 0.05$) in Hg levels.

3.4. Comparison of heavy metal concentrations between Wassa East district and Asutifi North (surface water, households, institutions and water points)

A comparison of heavy metals in surface water, households, institutions and water points from **the two** districts is shown in Table 4. In the surface water, there was no significant difference ($p > 0.05$) between the two districts for As and Hg levels. There was a significant difference ($p < 0.05$) for Fe and Mn levels between the two districts. The Fe levels were higher in surface water from the Wassa East District compared to the Asutifi North District, and the Mn levels were higher in surface water from the Asutifi North District compared to the Wassa East District.

In households, there was no significant difference ($p > 0.05$) between the two districts for Fe and Mn levels. There was a significant difference ($p < 0.05$) for As and Hg levels between the two districts. The As and Hg levels were higher in drinking water from the Wassa East District compared to the Asutifi North District.

In the institutions, there was no significant difference ($p > 0.05$) between the two districts for Fe levels. There was a significant difference ($p < 0.05$) for Mn, As and Hg levels between the two districts. The Mn, As and Hg levels were higher in drinking water from the Wassa East District compared to the Asutifi North District.

At the water points, there was no significant difference ($p > 0.05$) between the two districts for all the metals studies (Fe, Mn, As and Hg levels).

(a)

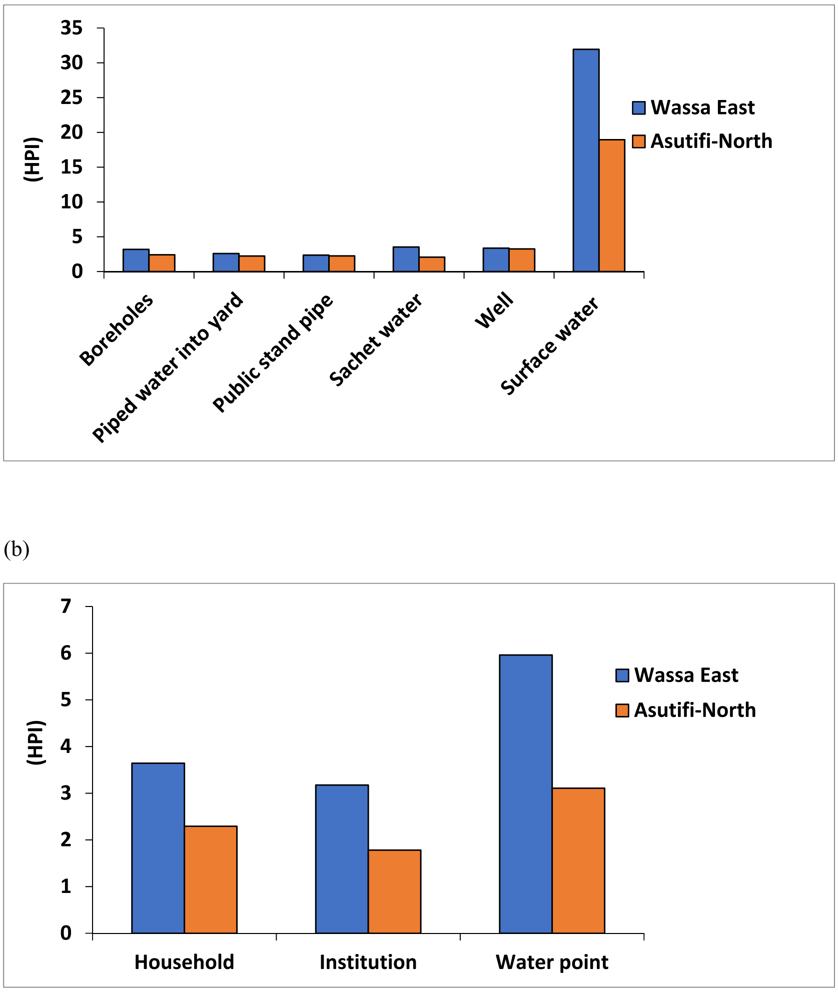

Fig. 2. (a) Heavy Metal Pollution Index (HPI) values for the different water types and (b) Heavy Metal Pollution Index (HPI) values for household, institutions and water points. All the HPI were less than the threshold value of 100.

3.5. Comparison of average heavy metal concentrations with WHO levels

Table 5 shows the comparison of average metal levels with the WHO permissible limits [35]. The average concentrations of metals analyzed at households, institutes and water points were all below the WHO recommended level, except for average Fe levels at waterpoints in Wassa East. In addition, the Fe levels in surface water in Wassa East and Asutifi North districts were all above the recommended WHO level.

3.5.1. Heavy metal pollution index (HPI) and water quality index (WQI)

The results of the HPI for the different water sources, and for water samples from Households, institutions and water points are shown in Fig. 2. The values obtained were below the critical limit of 100. This indicates that most of the water samples were not contaminated with heavy metals.

The results of the Water Quality Index (WQI) of the different water types (Table 6) indicate that the boreholes, piped water into yards, and public standpipes in both districts are suitable for drinking. The well and surface water in both districts can be described as very poor and unfit, respectively, and thus are not suitable as drinking water.

4. Discussion

The occurrence of higher Fe and Mn levels compared to other metals in different water types in the two districts has been reported in other studies in Ghana and around the world [9,10,28,36]. The high levels of Fe and Mn in the districts may be attributed to pH, oxidation and reduction conditions, as well as their abundance in soils and minerals [36–38]. The occurrence of lower Hg levels than As has also been reported by other studies in Ghana [10,20]. The metal levels in water resources are influenced by natural and anthropogenic factors [21,36–39]. In the present study, both districts have anthropogenic activities such as mining and farming, which may contribute to heavy metal pollution in surface and groundwater. These natural and anthropogenic factors affect the mobilization and dissolution of these metals in surface and groundwater [9,37,38].

In the present studies, the concentrations of metals in different water types showed different distributions in both districts. In the Wassa East district, higher levels of Fe, As and Hg were found in surface water compared to groundwater (wells and boreholes) and other water types. This has been reported in previous studies in the district and surrounding areas [10,20]. These studies showed that surface water is more exposed to metal contamination from human activities such as mining, industrial and agricultural waste, which are sources of heavy metals in the environment. Additionally, local geology may also play a role, as previous studies have demonstrated that it can impact the concentration of heavy metals in both surface water and groundwater [11,36]. In the Asutifi North district, the metal concentrations were similar across the different water types, except for higher levels of As and Hg in wells compared to boreholes, and other drinking water sources. This agrees with previous studies that showed that shallow groundwater is more contaminated than deep groundwater [40,41]. This disparity may be attributed to pollution from mining activities. For example, Hg is commonly used in gold mining by small-scale miners in these districts.

The concentrations of metals in drinking water collected from households, institutions and water points in both districts showed different patterns. The higher levels of As and Hg at the water points in Asutifi North district are because the water points include different water types. Water points are generally accessed by the general public, and this may contribute to higher levels of heavy metals at water points. Some studies have shown that urbanization and overpopulation can increase contaminant levels in the environment [34,42]. The institution had low metal levels because the water is primarily used by those within the institutes, resulting in less exposure to the general public. Another reason is that treated water (tap water) and borehole water are the main sources of water at the institution. Surface water, well water and other water types are rarely used at the institutes. In the Wassa East district, the lack of differences in metal levels among households, institutions and water points may be attributed to natural factors such as local geology or anthropogenic activities such as mining in the district and surrounding areas [10,11]. This may have resulted in elevated levels of heavy metals in the different drinking water sources used in these environments.

The comparison of metal concentrations between the two districts for drinking water in households, institutions, water points and surface water indicates that overall, drinking water from the Wassa East district is more contaminated than that from the Asutifi North district. The As and Hg in households and Mn, As and Hg at institutes in the Wassa East district were higher than in the Asutifi North

Table 6
The Water Quality Index (WQI) shows the water quality status of the different water types used in the two districts.

District	Water type	WQI	Status
Wassa East	Borehole	37.0817	Good water
	Piped water into yard	30.18652	Good water
	Public standpipe	39.02554	Good water
	Well	91.70074	Very poor water
	Surface water	207.4741	Unfit
Asutifi-North	Borehole	35.0428	Good water
	Piped water into yard	17.80748	Excellent water
	Public standpipe	20.54713	Excellent water
	Well	89.70787	Very poor water
	Surface water	131.3503	Unfit

district. However, there was no difference in metal levels between the water points in both districts. This is because the water points include all water types, some of which may have a higher concentration of heavy metals. This finding also suggests that public access to these water points may be a contributing factor to elevated metal levels at water points. In the surface water, Fe levels were higher in the Wassa East district than the Asutifi North district. In contrast, the Mn levels were higher in the Asutifi North district than the Wassa East district. The difference in Fe and Mn levels in the surface water in both districts may be due to the abundance of Fe and Mn in soils and rocks in these districts, as well as the prevailing pH and redox conditions in soils and rocks [36,38].

In the present study, the average metal levels compared with the WHO recommended levels indicate that Fe levels at water points in Wassa East and in surface water in both districts exceeded the permissible limits [35]. This is of concern since water collected from water points and surface water may be used as drinking water in some households. Although Fe is an essential metal needed by the body to control and treat anemia, when Fe levels exceed threshold levels, they can accumulate in organs and affect their function [17,43]. The occurrence of excess Fe in water also makes the water turbid and gives the water a metallic taste, which is not pleasant to consumers [39]. Mn, which is an essential metal, and As and Hg, which are non-essential metals, were within WHO recommended levels. In the present study, we also observed that some individual water points and surface water had metal levels exceeding the WHO levels, and thus drinking from these water points and surface water may expose people to the toxic effects of the different heavy metals.

The HPI for drinking water sources in households, institutions and water points in the two districts indicates that the drinking water resources were not polluted with heavy metals. This finding is different from other studies that reported an HPI exceeding 100 in coastal areas in the western region of Ghana and the Ejisu-Juaben Municipality, Ghana [5,44]. However, our results agree with other studies around the world where the HPI was less than 100 [1]. This difference and similarity may be due to the geology and anthropogenic factors in these areas. Another reason may be that the metals analyzed in this study are different from those in the previous study. The study by Appiah-Opong et al. [5], showed that the high HPI was mainly due to the high levels of Pb in the water sample.

The WQI shows that surface water and well water are unfit for drinking. This is mainly due to the high turbidity of the surface and well water. The physico-chemical parameters show that the turbidity of surface and well water was higher than WHO levels [35]. The main anthropogenic activity in these districts is mining. However, small-scale mining, which is rampant in these communities, may be responsible for the poor quality of the surface and well water. The findings are similar to other studies in India and Bangladesh where the WQI showed that ground water in some areas is unsuitable for drinking [2,4]. The limitations of the present study are that the effect of seasonality on water quality was not considered. In addition, the concentrations of only four metals were investigated. The inclusion of seasonality and analyzing more metals may have resulted in a different HPI for the water samples. Additionally, some metal concentrations may have exceeded the WHO recommended levels. Future research should investigate more metals and also include the effect of seasonality on water quality.

5. Conclusion

In conclusion, this study showed that levels of Fe and Mn were higher in all the drinking water samples collected compared to As and Hg. Fe, Mn, As and Hg were higher in drinking water from water points compared to households and institutions in the Asutifi North district. However, in the Wassa East district, there was no difference in metal levels in drinking water from water points, households and institutions. Surface and well water were more contaminated than other types of water. All the metals studied except Fe at water points in the Wassa East district and surface water from both districts were within the recommended WHO levels. The HPI indicates low heavy metal pollution, and the WQI indicates that wells and surface water are not suitable for drinking. Overall water quality in these districts needs to be improved, which involves reducing mining activities that pollute surface water and shallow ground water like wells. It is also recommended that surface water not be used as drinking water, as it is more polluted than groundwater and other water types investigated in this study. Additionally, it is recommended that the well water that is regularly used in these communities be treated before being used as drinking water. Furthermore, the supply of treated water (tap water) should be improved in these districts, along with regular monitoring of water quality.

CRediT authorship contribution statement

Juliet Ewool: Methodology, Data curation, Conceptualization. **Emmanuel R. Blankson:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Jones Kpakpa Quartey:** Formal analysis, Data curation, Conceptualization. **Rosina Kyerematen:** Funding acquisition, Conceptualization. **Francis Gbogbo:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Juliet Ewool, Emmanuel R. Blankson, Jones Kpakpa Quartey, Francis Gbogbo, Rosina Kyerematen reports financial support was provided by The Conrad N. Hilton Foundation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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