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Groundwater quality assessment in mining communities in Western and Central Regions of Ghana

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Abstract: The pollution of groundwater sources is a major issue globally, particularly for developing countries where the uncontrolled exploitation of natural mineral resources and human activities could lead to the pollution of water resources. The objective of this study was to examine the quality of groundwater in selected mining communities in the Central and Western regions of Ghana. A total of fifty (50) water samples collected from boreholes and wells in five mining communities; Ayanfuri, Abenabena, Nkonya, Forbinso, and Gyamang were analyzed for trace metals and physicochemical properties. The Water Quality Index (WQI) method was used to classify the various samples. Respondents expressed concerns about the smell and salty taste of groundwater. There was also high arsenic (1.028 mg/l and 1.048 mg/L), iron (0.303 mg/L and 0.304 mg/l), and cadmium (0.189 mg/l and 0.191 mg/l) pollution in the study area which requires urgent attention due to the potential adverse human health effects associated with exposure to high levels of these trace metals. The study revealed high turbidity in some groundwater samples in the study area making them unhealthy for domestic use. In the j WQI classification, all the groundwater samples apart from Nkonya (Nk-w1, Nk-w2, and Nk-site w) which were considered poor water were classified as good water. There is a need to control the levels of arsenic, iron, cadmium, and turbidity levels in groundwater in the study area, particularly in Nkonya. Community residents should be educated on the effects of groundwater pollution.

Keywords: Quality, Groundwater, Mining, Ghana, Heavy metal.

Introduction: Mining the process of extracting naturally existing minerals from the earth is considered the second oldest and most essential industry in the world after agriculture (Amponsah-Tawiah, 2011). The mining of gold alone has for decades employed most indigenous people and several countries with enormous economic development (Chuhan-Pole *et al.,* 2015). Hirwa *et al.* (2019) identified five stages of mining prospecting, exploration, development, exploitation, and reclamation. The African Union in 2009 reported that Africa has the most reserves of gold, platinum, diamonds, manganese, vanadium, and chromite in the world (Duncan, 2020). However, Africa does not enjoy the full benefits of this richness in mineral resources since it is heavily burdened by the environmental effects of mining (Saleem *et al.,* 2008). Many African nations that are blessed with mineral resources are still grappling with the several environmental challenges associated with increasing mining activities such as wastewater discharge, large amounts of mining waste, and dissipative losses among others (Duncan, 2020).

Gold mining has now become unpopular in Ghana because of the levels of pollution associated with it (Rajaee *et al.,* 2015). Afum & Owusu (2016) also reported that there is growing public concern about the condition of fresh waters in Ghana due to the rapidly growing nature of the small-scale mining industry. Several researchers have linked the pollution of some surface and groundwater bodies in Ghana to gold mining activities (Bempah *et al.,*2016; Cobbina *et al.,* 2015; Duncan, 2020; Mensah *et al.,* 2015). Poor water quality has been linked to public health concerns, mainly through the transmission of water-borne diseases (Wu *et al.,* 2017). To reduce water-related diseases and to improve health in Ghana, several boreholes and wells have been built in several rural communities and mining-affected areas by the private sector, NGOs, and the Ghanaian government. However, the monitoring of water quality generally ceases once a water source has been improved (Rossiter *et al.,*2010). Even though almost three-fourths of the earth is made of water, only a small proportion of it is safe for drinking purposes (Alshikh, 2011). Water is an essential resource for all forms of life and access to a reliable source of drinking water is now recognized by the United Nations as a human right (Cobbina *et al.,* 2015). However, in rural communities and particularly in places where access to clean water is limited, people mostly use untreated water for domestic purposes, including drinking (Macdonald *et al.,* 2015; Cobbina *et al.,*2013). WHO/UNICEF (2010) reported that almost all of the about 884 million people who do not have access to safe drinking water sources are from developing countries.

Water that is used for drinking purposes must have some level of quality and there are key physical, biological, and chemical parameters that determine this quality. The biological parameters include such things as microbial populations; the chemical parameters include cations and anions; and the physical parameters include such characteristics as taste, smell, color, pH, turbidity, temperature, total dissolved solids, electrical conductivity, total suspended solids and total alkalinity (Asamoah & Amorin, 2011). The protection and management of water quality plays a vital role in agriculture production, environmental sustenance poverty reduction, and sustainable economic development (Singh & Hussian, 2016). It is possible to have seasonal variations in the quality of water but the importance of safe and reliable sources of water cannot be over-emphasized. It is therefore important that water is readily available when needed, not just in the right quantity, but also in the right quality devoid of pollutants to meet the various needs for which it is naturally or artificially applied (Akankali *et al.,* 2017). The storehouse of freshwater and the most commonly used renewable source of water is groundwater (Krishan *et al.,* 2016). Groundwater is an important source of water supply throughout the world. Groundwater occurs almost everywhere beneath the earth's surface not in a single widespread aquifer but in thousands of local aquifer systems and compartments that have similar characteristics (Singh & Hussian, 2016). Groundwater consists of over 90% of the freshwater resources on earth and it is an essential storage of good quality water (Alshikh, 2011). The natural filtration through soil and sediments makes the groundwater free from organic impurities (Saleem *et al.,* 2016).

According to Gao *et al.* (2020), access to clean and safe groundwater is a fundamental requirement for sustainable human and social development. There is an ever-increasing need for enhanced management of surface and groundwater because they are the most readily available source of water for human use, yet the most polluted as a result of anthropogenic activities (Ojekunle & Lateef, 2017). Anthropogenic activities that also pollute water bodies include excessive use of fertilizers and pesticides in agricultural areas (Singh & Hussian, 2016). Unsafe groundwater adversely affects the economy and hinders improvement in the living conditions of rural people (Batabyal & Chakraborty, 2015). Yet groundwater quality and quantity are worsening at a very fast rate due to human activities like mining (Saleem *et al.,* 2016). Water contamination from mining activities results from the discharge of effluents, which contain toxic chemicals such as cyanide and other organic chemicals used in the processing of mineral ores. These chemicals together may result in effluent with high acid levels which can either seep into underground water or flow into surface water bodies, posing a threat to the nearby communities particularly those that depend on such water bodies for drinking and other domestic purposes (Duncan, 2020). Trace metal is any metallic element that has a relatively low density and is not toxic or poisonous at low concentrations. However, excessive concentrations of these trace metals can become detrimental to organisms with unusually high concentrations becoming toxic to aquatic organisms. Trace metals are characterized by concentrations lower than 1mg in natural waters which are obligatory by man in amounts ranging from 50 micrograms to 18 milligrams per day. Acting as catalytic or structural components of larger molecules, they have specific functions that are requisite for life (Kulaksız & Bau, 2011). Heavy metals exist as natural constituents of the earth's crust and are persistent environmental contaminants because they cannot be degraded or destroyed (Lenntech, 2004).

Some metals are essential to sustain life-calcium, magnesium, potassium and sodium must be present for normal body functions. Also, cobalt, copper, iron, manganese, molybdenum, and zinc are required at low levels as catalysts for enzyme activities (Alshikh, 2011). Many of these compounds exist naturally, but their concentration has increased as a result of anthropogenic activities (Huang *et al.,* 2014). Health risks of trace metals include reduced growth and development, cancer, organ damage, nervous system damage, and in extreme cases, death. Exposure to some metals, such as mercury and lead, may also cause the development of autoimmunity, in which a person's immune system attacks its cells. Heavy metals become toxic when they are not metabolized by the body and accumulate in the soft tissues (Malassa *et al.,* 2013). The leaching of heavy metal oxides into groundwater bodies also poses a threat to communities that depend on such groundwater sources (Huang *et al.,* 2014).

There are two major mining activities practiced in the Upper Denkyira West and Wassa Amenfi East communities in the Western and Central regions of Ghana; large-scale mining that uses sophisticated machines and methods of mining and small-scale mining that makes use of simple tools to extract gold from the land. These mining activities have the potential to cause heavy metal pollution of both surface and groundwater resources in these communities (Attiogbe & Nkansah, 2017; Bempah *et al.,* 2016; Duncan, 2020). Bempah *et al.* (2016) examined heavy metal concentrations in groundwater in communities in the southwestern parts of the Ashanti Region. They found that the levels of As and Fe were higher than the WHO permissible limits.

Groundwater is potable but unsuitable for drinking in isolated locations due to high levels of As and Zn (Gyamfi *et al.,* 2019). Macdonald *et al.* (2015) found that sites with associated artisanal small-scale gold mining (ASGM) activities had water qualities that did not meet Ghana's national standards for drinking water, with manganese at particularly high concentrations. The results of the above studies showed major variability in the concentrations of various trace metals in groundwater at various geographical locations. The variability in trace metals and physicochemical properties of groundwater in various parts of the country emphasizes the need for regular monitoring of all groundwater sources, especially in mining communities (Gyamfi *et al.,* 2019; Kulinkina *et al.,* 2017).

Meanwhile, the selected mining communities have bitterly complained about the poor quality of their water sources such as the oil sheeny, smell/odor, taste, salt, and color in the water (Asamoah *et al.,* 2011) the five study areas communities largely depend on wells and boreholes sources for drinking purposes. In a news article published by Graphic Online in October-03-2015, residents of the Ayanfuri communities protested bitterly against the unfair treatment of their water bodies which influences the water quality by Perseus Mining Ghana Limited (Aziz, 2015). Also, in another news article published by Modern Ghana in its special report on May-26-2020, the people of Ayanfuri blamed the operations of Perseus Mining Ghana Limited for the acute water shortage and groundwater pollution in surrounding communities, which affected the economic activities of the inhabitants (Aubyn, 2020).

However, studies on trace metal concentrations and the physicochemical properties of groundwater in Ayanfuri and its environs are scantily documented. Also, despite the worldwide adoption of WQI as an effective way of making conclusions about the quality of drinking water has not been sufficiently utilized in Ghana to assess groundwater quality. Finally, there is a paucity of literature on the perceptions of community residents about groundwater quality in Ghana, even though such perceptions are a reflection of problems associated with groundwater (Kulinkina *et al.,* 2017). The study sought to assess groundwater quality in mining communities in the Central and Western regions of Ghana

METHODOLOGY

Selection of sampling points

The study was conducted in five mining communities in the Wassa Amenfi East and Upper Denkyira-West Districts of the Western and Central Regions of Ghana respectively. These five communities were selected because of the mining activities in the area. A total of 25 sampling points were identified and selected in the five communities. A total of fifty (50) samples were collected from the 25 sampling points, which included 10 boreholes from the communities, and 15 hands dug wells from the communities. The sampling points were assigned codes as shown in Table 1

Table 1: Water sampling point

Sampling location	Code	Total number of samples
Abenabena	Ab-borehole 1	2
	Ab-borehole 2	2
	Ab-well 1	2
	Ab-well 2	2
	Ab-site well	2
Ayanfuri	Ay-borehole 1	2
	Ay-borehole 2	2
	Ay-well 1	2
	Ay-well 2	2
	Ay-site	2
Forbinso	Fb-borehole 1	2
	Fb-borehole 2	2
	Fb-well 1	2
	Fb-well 2	2
	Fb-site well	2
Gyamang	Gy-borehole 1	2
	Gy-borehole 2	2
	Gy-well 1	2
	Gy-well 2	2
	Gy-site well	2
Nkonya	Nk-borehole 1	2
	Nk-borehole 2	2
	Nk-wel 1	2
	Nk-well 2	2
	Nk-site well	2

Sample collection from groundwater

The bottles used for sample collection were 500 ml plastic bottles. They were soaked in nitric acid the night before sample collection, wash with liquid soap, rinse three times with distilled water and dry in a cupboard. The method used for this study is the Water Research Commission (WRC) guideline (WRC, 2000). In other to prevent light from affecting the physicochemical parameters of the water samples, the plastic bottles were covered with black polythene bags. The bottles were acid sterilized bottles and before the collection of a sample, the bottles were rinsed five times with water from the borehole or well. Samples were taken from the boreholes after it has been pumped for five (5) minutes. For samples from the wells, water was drawn using a sterilized bailer and poured into the bottles. A lid was used to immediately cover the bottles and appropriately labeled with the sample code and date of sampling.

Sample preservation technique

In order to reduce errors and the possibility of unreliable results as a result of contamination, a trip blank that was prepared with distilled water was added to the samples and properly labeled. These were done to assess the extent of the contamination during the collection of samples at the field. The collected samples in the field and trip blanks were kept in ice chest at 4 OC and were immediately transported to the Soil Testing Laboratory of Soil Research Institute, Kwadaso Kumasi for immediate analysis.

Analysis of water samples

Temperature, Total Dissolved Solids, pH, turbidity and Electrical Conductivity were measured using appropriate water quality measuring instruments. The concentration of trace metals (Cd, Fe, Pb, Mn, Cu, As, and Zn) were determined using Spectra AA220 Atomic Absorption Spectrophotometer (AAS) (Cobbina *et al.,* 2015), 50 ml of the water samples was filled into 100 ml volumetric flask. 30 ml concentrated HNO3 was added and 20 ml concentration of hydrochloric acid (HCl) was added in a digestion tube, heated in digestion block at 105 degree Celsius for 30 minutes (Alloway, 2012). The solution was cooled, 5 ml of Kl were added for 1 hour, and a minimum amount of Ascorbic acid powder was added to discharge any yellow colour of iodine. Filled into a 50 ml volumetric flask and made to the mark with distilled water. They were then analysed for their metal levels, Arsenic were determined using hydride generation AAS. Triplicate analyses of samples, blanks and standards were done. Samples that were not analysed immediately were stored in a fridge (Alloway, 2012). Reliability of the results was checked using individual elemental standards (certified reference materials, CRMs) by the IRMM (Joint Research Centre European Commission) for a standard Reliability of chemical analysis. Standards solutions (5, 10 and 15 mg/L) were prepared by dilution of 1000 mg/L stock solutions. Approximately 30 ml of each standard was taken through the treatment processes and their concentrations were measured.

Statistical Analysis

The data on were summarized according to town of sample. Means and standard deviations were estimated using SPSS Version 25. The mean concentration for each site was then compared to the WHO and EPA-Gh guideline values for water quality. Also, One-Way ANOVA was used to explore differences in mean concentrations of the physicochemical properties among the five towns. Tukey Post-Hoc analyses were performed in cases where significant differences were found among towns in the ANOVA test. Statistical analyses were done at the 0.05 % level of significance.

RESULTS

Properties of Groundwater in the Study Areas

Concentration of Trace Metals in Groundwater in Abenabena

The levels of trace metals in ground water from the various sampling sites have been presented in Table 2. The range of the levels of zinc (0.038-0.042 mg/L), copper (0.114-0.236 mg/L), manganese (0.086-0.17 mg/L), and lead (0.002-0.003 mg/L) were all below the WHO/EPA guideline values. The levels of arsenic (0.64-1.31 mg/L) and cadmium (0.124-0.144 mg/L) were above the WHO and EPA acceptable limits for potable water. However, lead levels in samples from three sites (Ab-w1, Ab-w2 and Ab-site) were above the EPA-Gh guideline value of 0.3 mg/L.

Table 2: Concentration of Trace Metals in Groundwater in Abenabena

Parameters	Site Code					Guideline Values	
	Ab-b1	Ab-b2	Ab-w1	Ab-w2	Ab-site	WHO[a]	EPA[b]
Zinc (mg/L)	0.038	0.04	0.042	0.04	0.041	N.A	5
Arsenic (mg/L)	0.64	0.79	1.31	1.24	1.26	0.01	0.01
Cadmium (mg/L)	0.127	0.124	0.141	0.14	0.144	0.003	0.1
Copper (mg/L)	0.117	0.114	0.221	0.22	0.236	2	5
Iron (mg/L)	0.159	0.16	0.466	0.456	0.463	N.A	0.3
Manganese (mg/L)	0.17	0.16	0.086	0.092	0.101	0.4	N.A
Lead (mg/L)	0.003	0.002	0.002	0.003	0.003	0.01	0.1

[a](WHO 2017); [b](EPA-Gh, Environmental Protection Agency).

Physicochemical Properties of Groundwater in Abenabena

The results of the physicochemical properties of groundwater in Abenabena have been presented in Table 3. All the samples were slightly acidic with pH values ranging from 5.8 to 6.04. All the pH values of the samples were outside of the WHO range of 6.6-8.5 while the pH values from Ab-b1 (5.8), Ab-b2 (5.82) and Ab-w2 (5.97) were outside of the EPA-Gh range of 6-9. The mean Turbidity level across samples was 7.476 NTU which is above the WHO/EPA guideline value of 5 NTU. A close inspection of Table 3 reveals that Turbidity of two samples (Ab-w1 and Ab-w2) were above the WHO/EPA guideline values. Also, the levels of T.S.S (4.0-12.1 mg/L), E.C (240-276 µS/cm), and T.D.S (148-170 mg/L) from all the samples were below the WHO/EPA guideline values. However, the levels of D.O (5.52-5.91 mg/L) from all the samples were above the WHO/EPA guideline values.

Table 3: Physicochemical Properties of Groundwater in Abenabena

Parameters	Site Code					Guideline Values	
	Ab-b1	Ab-b2	Ab-w1	Ab-w2	Ab-site	WHO[a]	EPA[b]
pH	5.8	5.82	6	5.97	6.04	6.5-8.5	6-9
Turbidity (NTU)	2.64	2.63	15.3	15.42	1.39	5	5
T.S.S (mg/L)	4	4	11	12.01	12.11	50	50
E.C (µS/cm)	240	243	270	275	276	1,500	1,500
D.O (mg/L)	5.58	5.52	5.81	5.84	5.91	5	N.A
T.D.S (mg/L)	149	148	167	168	170	1000	1,000

[a](WHO 2017); [b](EPA-Gh, Environmental Protection Agency).

Concentration of Trace Metals in Groundwater in Nkonya

The levels of trace metals in groundwater samples collected from Nkonya have been presented in Table 4. In terms of the trace metals, the levels of Zn (0.053-0.056 mg/L), Cu (0.22-0.24 mg/L), Mn (0.004-0.006 mg/L), and Pb (0.001-

0.004 mg/L) were all below the WHO and EPA-Gh limits for drinking water. However, the levels of As (0.66-1.59 mg/L) and Cd (0.107-0.191 mg/L) were all above the WHO and EPA-Gh limits for drinking water. Also, the levels of Fe in samples from Nk-w1 (0.301 mg/L), Nk-w2 (0.303 mg/L), and Nk-site (0.304 mg/L) were marginally above the EPA-Gh limit for drinking water.

Table 4: Concentration of Trace Metals in Groundwater in Nkonya

	Site Code					Guideline Values	
Parameters	Nk-b1	Nk-b2	Nk-w1	Nk-w2	Nk-site	WHO[a]	EPA[b]
Zinc (mg/L)	0.053	0.054	0.055	0.055	0.056	N.A	5
Arsenic (mg/L)	1.56	1.59	0.66	0.66	0.67	0.01	0.01
Cadmium (mg/L)	0.191	0.189	0.107	0.109	0.111	0.003	0.1
Copper (mg/L)	0.22	0.22	0.234	0.24	0.236	2	5
Iron (mg/L)	0.148	0.15	0.301	0.303	0.304	N.A	0.3
Manganese (mg/L)	0.005	0.004	0.005	0.005	0.006	0.4	N.A
Lead (mg/L)	0.003	0.004	0.001	0.001	0.002	0.01	0.1

[a](WHO 2017); [b](EPA-Gh, Environmental Protection Agency).

Physicochemical Properties of Groundwater in Nkonya

The results of the physicochemical properties of groundwater in Nkonya have been presented in Table 5. All the water samples from Nkonya were acidic and outside the WHO/EPA-Gh range for portable water. The pH of samples from the sites was in the range of 4.0 to 4.23 and a mean pH of 4.126 was recorded. Also, the level of D.O from the samples ranged from 6.6 to 8.5 mg/L and were above the WHO guideline value of 5 mg/L. Additionally, the turbidity of samples from Nk-w1 (25.9 NTU), Nk-w2 (25.91 NTU), and Nk-site (25.89 NTU) were above the WHO/EP-Gh guideline values. However, the levels of T.S.S (0-27 mg/L), Ec (50-173 µS/cm), and T.D.S (31-106 mg/L) were all below the WHO/EPA-Gh guideline values.

Table 5: Physicochemical Properties of Groundwater in Nkonya

	Site Code					Guideline Values	
Parameters	Nk-b1	Nk-b2	Nk-w1	Nk-w2	Nk-site	WHO[a]	EPA[b]
pH	4	4	4.2	4.2	4.23	6.5-8.5	6-9
Turbidity (NTU)	0.95	0.95	25.9	25.91	25.89	5	5
T.S.S (mg/L)	0	0	26	26	27	50	50
E.C (µS/cm)	50	51	170	173	171	1,500	1,500
D.O (mg/L)	8.48	8.5	6.6	6.6	6.63	5	N.A
T.D.S (mg/L)	31	32	105	104	106	1000	1,000

[a](WHO 2017); [b](EPA-Gh, Environmental Protection Agency).

Concentration of Trace Metals in Groundwater in Ayanfuri

The levels of trace metals in groundwater samples from Ayanfuri have been summarized in Table 6. The results reveal that the levels of As (0.78-0.79 mg/L) and Cd (0.111-0.172 mg/L) were above the WHO/EPA-Gh limits for portable water. However, the levels of Zn (0.087-0.089 mg/L), Cu (0.21-0.219 mg/L), Fe (0.148-0.161 mg/L), Mn (0.005-0.009 mg/L), and Pb (0.002-0.003 mg/L) from all the sites were below the WHO/EPA-Gh limits.

Table 6: Concentration of Trace Metals in Groundwater in Ayanfuri

	Site Code					Guideline Values	
Parameters	Ay-b1	Ay-b2	Ay-w1	Ay-w2	Ay-site	WHO[a]	EPA[b]
Zinc (mg/L)	0.087	0.087	0.087	0.087	0.089	N.A	5
Arsenic (mg/L)	0.78	0.78	0.78	0.78	0.79	0.01	0.01
Cadmium (mg/L)	0.131	0.134	0.164	0.17	0.172	0.003	0.1
Copper (mg/L)	0.21	0.214	0.219	0.214	0.216	2	5
Iron (mg/L)	0.148	0.157	0.149	0.152	0.161	N.A	0.3
Manganese (mg/L)	0.005	0.006	0.008	0.007	0.009	0.4	N.A
Lead (mg/L)	0.002	0.002	0.002	0.002	0.003	0.01	0.1

[a](WHO 2017); [b](EPA-Gh, Environmental Protection Agency).

Physicochemical Properties of Groundwater in Ayanfuri

The results of the physicochemical properties of groundwater in Ayanfuri have been presented in Table 7. The results revealed that the pH of the samples from all the sites were slightly acidic and fall outside the WHO/EPA-Gh range. The pH ranged from 5.17 to 5.42 and the mean pH was 5.304. Also, the levels of D.O from all the sites ranged from 8.67 to 9.24 and were above the WHO guideline value. However, the levels of turbidity (0.57-0.64 NTU), T.S.S (5-5.35 mg/L), Ec (130 to 142 µS/cm), and T.D.S (80-89 mg/L) were within the WHO/EP-Gh limits for portable water.

Table 7: Physicochemical Properties of Groundwater in Ayanfuri

	Site Code					Guideline Values	
Parameters	Ay-b1	Ay-b2	Ay-w1	Ay-w2	Ay-site	WHO[a]	EPA[b]
pH	5.17	5.2	5.34	5.42	5.39	6.5-8.5	6-9
Turbidity (NTU)	0.6	0.59	0.64	0.57	0.59	5	5
T.S.S (mg/L)	5.2	5.35	5.25	5	5.3	50	50
E.C (µS/cm)	132	130	138	139	142	1,500	1,500
D.O (mg/L)	8.76	8.67	8.89	9.24	9.18	5	N.A
T.D.S (mg/L)	80	81	84	87	89	1000	1,000

[a](W.H.O, 2017); [b](EPA-Gh, Environmental Protection Agency, n.d.).

Concentration of Trace Metals in Groundwater in Gyamang

The levels of trace metals in groundwater samples from Gyamang have been presented in Table 8. The levels of Cd (0.18-0.186 mg/L) from all the sites are above the WHO/EPA-Gh guideline values for portable water. Also, the levels of Fe from Gy-w1 (0.301 mgl) and Gy-site (0.31 mg/L) are marginally above the EPA-Gh acceptable limit for portable water. However, the levels of Zn (3-3.23 mg/L), As (0.001-0.001 mg/L), Cu (0.002-0.008 mg/L), Mn (0.023-0.041 mg/L), and Pb (0.002-0.004 mg/L) were within the WHO/EPA-Gh acceptable limits for portable water.

Table 8: Concentration of Trace Metals in Groundwater in Gyamang

	Site Code					Guideline Values	
Parameters	Gy-b1	Gy-b2	Gy-w1	Gy-w2	Gy-site	WHO[a]	EPA[b]
Zinc (mg/L)	3.231	3.119	2.999	2.999	3.121	N.A	5
Arsenic (mg/L)	0.001	0.001	0.001	0.001	0.001	0.01	0.01
Cadmium (mg/L)	0.184	0.181	0.18	0.182	0.186	0.003	0.1
Copper (mg/L)	0.002	0.002	0.005	0.006	0.008	2	5
Iron (mg/L)	0.289	0.292	0.301	0.298	0.31	N.A	0.3
Manganese (mg/L)	0.023	0.025	0.037	0.041	0.039	0.4	N.A
Lead (mg/L)	0.002	0.002	0.002	0.003	0.004	0.01	0.1

[a](WHO 2017); [b](EPA-Gh, Environmental Protection Agency).

Physicochemical Properties of Groundwater in Gyamang

The results of the physicochemical properties of groundwater in Gyamang have been presented in Table 9. The pHs of the water samples ranged from 5.1 to 5.14 and were outside of the WHO/EPA-Gh acceptable range for drinking water. Also, the levels of D.O in all the samples ranged from 8.5 to 8.53 mg/L and were above the WHO guideline value for portable water. However, the turbidity (0.43-0.46 NTU), T.S.S (2-2.05 mg/L), EC (57.6-58 µS/cm), and T.D.S (28.1-28.3 mg/L) were within the WHO/EPA-Gh guideline values for portable water.

Table 9: Physicochemical Properties of Groundwater in Gyamang

	Site Code					Guideline Values	
Parameters	Gy-b1	Gy-b2	Gy-w1	Gy-w2	Gy-site	WHO[a]	EPA[b]
pH	5.1	5.12	5.1	5.14	5.11	6.5-8.5	6-9
Turbidity (NTU)	0.44	0.46	0.45	0.44	0.43	5	5
T.S.S (mg/L)	2	2	2.05	2.03	2.01	50	50
E.C (µS/cm)	57.6	57.8	57.79	58	57.65	1,500	1,500
D.O (mg/L)	8.51	8.51	8.52	8.5	8.53	5	N.A
T.D.S (mg/L)	28.1	28.3	28.2	28.1	28.15	1000	1,000

[a](WHO 2017); [b](EPA-Gh, Environmental Protection Agency).

Concentration of Trace Metals in Groundwater in Forbinso

The levels of trace metals in groundwater samples from Forbinso have been presented in Table 10. the results show that the levels of Cd from all the sites ranged from 0.155 to 0.272 mg/L and were above the WHO/EPA-Gh limits for portable water. Also, the levels of Fe at Fb-w1 (0.364 mg/L), Fb-w2 (0.361 mg/L), and Fb-site (0.375 mg/L) were above the guideline value of EPA-Gh. However, the levels of Zn (3.45-4 mg/L), As (0-0.001 mg/L), Cu (0.003-0.006 mg/L), Mn (0.019-0.039 mg/L), and Pb (0.002-0.003 mg/L) were within the WHO/EPA-Gh acceptable limits for portable water.

Table 10: Concentration of Trace Metals in Groundwater in Forbinso

	Site Code					Guideline Values	
Parameters	Fb-b1	Fb-b2	Fb-w1	Fb-w2	Fb-site	WHO[a]	EPA[b]
Zinc (mg/L)	3.499	3.546	3.448	3.848	3.999	N.A	5
Arsenic (mg/L)	0.0	0.0	0.0	0.0	0.001	0.01	0.01
Cadmium (mg/L)	0.155	0.163	0.258	0.267	0.272	0.003	0.1
Copper (mg/L)	0.003	0.003	0.005	0.005	0.006	2	5
Iron (mg/L)	0.138	0.142	0.364	0.361	0.375	N.A	0.3
Manganese (mg/L)	0.019	0.024	0.035	0.032	0.039	0.4	N.A
Lead (mg/L)	0.003	0.002	0.003	0.003	0.002	0.01	0.1

[a]*(WHO 2017);* [b]*(EPA-Gh, Environmental Protection Agency).*

Physicochemical Properties of Groundwater in Forbinso

The results of the physicochemical properties of groundwater in Abenabena have been presented in Table 11. The samples from all the sites were slightly acidic with pH values ranging from 5.18 to 5.2. These values were outside of the WHO/EPA-Gh range of pH for portable water. Also, the levels of D.O from all the sites ranged from 8.48 to 8.5 mg/L and were above the WHO guideline value for portable water. However, the turbidity (0.98-1 NTU), T.S.S (4-4 mg/L), EC (38.6-38.8 µS/cm), T.D.S (16.4 to 19.4 mg/L) were within the WHO/EPA-Gh limits for portable water.

Table 11: Physicochemical Properties of Groundwater in Forbinso

	Site Code					Guideline Values	
Parameters	Fb-b1	Fb-b2	Fb-w1	Fb-w2	Fb-site	WHO[a]	EPA[b]
pH	5.18	5.2	5.19	5.18	5.19	6.5-8.5	6-9
Turbidity (NTU)	0.98	1	0.99	0.98	0.98	5	5
T.S.S (mg/L)	4	4	4	4	4	50	50
E.C (µS/cm)	38.6	38.8	38.8	38.6	38.7	1,500	1,500
D.O (mg/L)	8.5	8.49	8.49	8.48	8.5	5	N.A
T.D.S (mg/L)	19.34	19.38	19.35	19.36	16.38	1000	1,000

[a]*(WHO 2017);* [b]*(EPA-Gh, Environmental Protection Agency).*

Comparisons of the Characteristics of Groundwater among the five Towns

The results of the One-Way ANOVA test have been presented on Table 12. Also, the descriptive results of the One-Way ANOVA and the Tukey Post Hoc comparisons can be found in Appendix A. The ANOVA comparisons on As and T.S.S returned undefined results since the minimum levels and standard deviations of As and T.S.S at Forbinso and

Nkonya respectively were zero (0). Also, there was no evidence of a statistically significant difference in the mean Pb levels among the five towns (p = 0.708). However, there were statistically significant differences in the mean levels of all the remaining characteristics of groundwater among the five towns (p < 0.001). The descriptive results and the Post Hoc test showed that the mean levels of Zn at Gyamang and Forbinso were significantly higher than the mean levels in the remaining three towns (p < 0.001). Also, the mean level of Cd was significantly higher at Forbinso than Abenabena (p < 0.01), Nkonya (p < 0.05) and Ayanfuri (p < 0.05). Additionally, the mean levels of Cu at Abenabena, Nkonya and Ayanfuri were significantly higher than at Gyamang and Forbinso (p < 0.001). Moreover, the differences found in Fe levels among the towns was as a result of the difference between Abenabena (0.3408 mg/L) and Ayanfuri (0.1534 mg/L) with p = 0.053. The mean level of Mn was found to be significantly higher at Abenabena than the remaining four towns (p < 0.001). The mean pH level at Nkonya was found to be significantly lower than those of all the other towns (p < 0.001). Also, the mean turbidity at Nkonya was found to be significantly higher than Ayanfuri, Gyamang and Forbinso (p<0.05). The mean level of E.C was found to be significantly higher at Abenabena than the remainder of the towns (p < 0.001). Additionally, mean E.C levels at Nkonya and Ayanfuri were found to be significantly higher than at Gyamang and Forbinso. The mean levels of D.O at Ayanfuri, Gyamang and Forbinso were found to be significantly higher than at Abenabena and Nkonya. The T.D.S at Abenabena was significantly higher than in the remaining four towns (p < 0.001).

Table 4.12 One-Way ANOVA of the Properties of Groundwater in the Five Communities

Parameters	F	df1	df2	P
Zinc (mg/L)	2207.612	4	9.45	< .001
Arsenic (mg/L)	NaN	4	NaN	NaN
Cadmium (mg/L)	28.353	4	8.3	< .001
Copper (mg/L)	4172.436	4	9.09	< .001
Iron (mg/L)	219.951	4	8.97	< .001
Manganese (mg/L)	29.896	4	8.64	< .001
Lead (mg/L)	0.544	4	9.79	0.708
pH	149.17	4	8.74	< .001
Turbidity (NTU)	1486.694	4	9.24	< .001
T.S.S (mg/L)	NaN	4	NaN	NaN
E.C (µS/cm)	11296.8	4	8.92	< .001
D.O (mg/L)	273.511	4	9.03	< .001
T.D.S (mg/L)	411.605	4	8.02	< .001

NaN = Not a number (meaning an undefined result was obtained).

Water Quality Index (WQI) of Ground Water in the Study Areas

The results of the WQI estimation and sample classification have been presented in Table 13. From the results, the estimated WQI ranged from 53.3 to 127.7. Also, the water from the various samples was put under two classifications; good water and poor water. The samples from 22 out of the 25 samples (thus 88 % of the samples) were classified as good water based on their WQI estimates. However, samples from Nk-w1 (127.4), Nk-w2 (127.4) and Nk-site-w (127.7) were classified as poor water based on their WQI estimates. The average WQI estimate across all samples was also classified as good water.

Table 13: Water Quality Index (WQI) and Classification

Site	WQI	Classification	Site	WQI	Classification
Ab-b1	53.6	Good water	Ay-w2	63.0	Good water
Ab-b2	53.3	Good water	Ay-site-w	62.8	Good water
Ab-w1	95.1	Good water	Gy-b1	55.8	Good water
Ab-w2	95.7	Good water	Gy-b2	55.9	Good water
Ab-site-w	53.8	Good water	Gy-w1	55.9	Good water
Nk-b1	54.8	Good water	Gy-w2	55.8	Good water
Nk-b2	54.9	Good water	Gy-site-w	55.9	Good water
Nk-w1	127.4	Poor water	Fb-b1	57.4	Good water
Nk-w2	127.4	Poor water	Fb-b2	57.4	Good water
Nk-site-w	127.7	Poor water	Fb-w1	57.4	Good water
Ay-b1	59.9	Good water	Fb-w2	57.2	Good water
Ay-b2	59.5	Good water	Fb-sit-w	57.3	Good water
AY-b1	61.2	Good water			

DISCUSSION

The results on the levels of trace metals in groundwater in the study communities varied from town to town for the various metals. In most cases the concentrations of the trace metals were within WHO and EPA Ghana guideline limits for portable water. The range of levels of zinc (0.038 to 3.999 mg/L), copper (0.002 to 0.24 mg/L), manganese (0.004 to 0.17 mg/L), and lead (0.001 to 0.004 mg/L) were all below WHO and EPA Ghana the acceptable limits for drinking water. This situation is desirable given the potential health risks of exposure to these trace metals. For instance exposure to high levels of copper could lead to damage to essential body organs such as the kidneys and liver (Yolcubal *et al.,* 2016). Also, exposure to lead among children is associated with cognitive development problems such as learning disability (Cobbina *et al.,* 2015). The study found that levels of arsenic and iron from some sites were above WHO/EPA Ghana guideline values for portable water. The presence of high levels of arsenic in some sites could be due to the incessant use of arsenic-containing substances in the processing of ore (Kwesi *et al.,* 2023; Bempah *et al.,* 2016). Long term exposure to arsenic could cause skin disorders such as skin cancer, and short term effects are edema, gastrointestinal and upper respiratory symptoms (Hadzi *et al.,* 2018). The high presence of iron in groundwater from some of the sites could be due to weathering of the rock systems in the study area, discharge of mining waste and acid mine drainage. These sources of iron have been cited in the literature as common sources of iron in groundwater, especially in mining areas (Hirwa *et al.,* 2019; Adimalla *et al.,* 2018; Alshikh, 2011). Also, the study found that the levels of cadmium exceeded WHO (0.003) and EPA (0.1) Ghana guideline values for potable water in all samples. The high levels of cadmium in groundwater in the study area is worrying and requires urgent attention because the intake of high levels of cadmium could result in toxicity to the kidney and skeletal system and may be associated with an increased risk of hypertension and cardiovascular disease (Hamid *et al.,* 2019). On the physicochemical properties of groundwater in the study area, it was found that that the T.S.S ranged from 0 27 mg/L, E.C ranged from 38.6 276 µS/cm, and T.D.S ranged from 16.38 170 mg/L. The levels of all these parameters were within WHO/EPA Ghana acceptable limits for potable water. The generally low levels of these parameters are possible indication of the occurrence of young or recharging groundwater since high values of T.S.S, EC and TDS are mostly associated with old or discharging groundwater (Anim-Gyampo *et al.,* 2018). The possibility of the occurrence of adverse health effects on humans are therefore unexpected (Nishtha, 2012). The pH of all samples was slightly acidic ranging from 4.0 to 6.0 and in most cases fell outside of WHO and EPA Ghana guideline values for potable water. Lower values in pH are indicative of high acidity, which can be caused by the deposition of acid forming substances in precipitation. A high organic content will tend to decrease the pH because of the carbonate chemistry. As microorganisms break down organic material, the by product will be CO2 that will dissolve and equilibrate with the soil forming carbonic acid (H2CO3) (Howladar *et al.,* 2017). Other organic acids such as humic and fluvic acids can also result from organic decomposition (Alshikh, 2011). The levels of turbidity ranged from 0.43 to 25.91 NTU. Turbidity levels exceeded the maximum allowable limits for portable water in five samples (Ab-w1, Ab-w2, NK-w1, Nk-w2, and Nk-site). Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates. The more total suspended solids in the water, the murkier it seems and the higher the turbidity. Turbidity is considered as a good measure of the quality of water. Groundwater from Ab-w1, Ab-w2, NK-w1, Nk-w2, and Nk-site may present significant health implications for the health of people who use them for domestic activities since turbidity levels above 5 NTU is not safe for consumption (WHO, 2017). The levels of dissolved oxygen were high in all samples, ranging from 5.52 to 9.24 mg/L. A high dissolved oxygen (DO) level in a ground water source is good because it makes drinking water taste better (Mazhar & Ahmad, 2020). However, high DO levels speed up corrosion in water storage containers and pipes (Saleem *et al.,* 2016). For this reason, it is essential to use water with the least possible amount of dissolved oxygen. The types of groundwater samples based on the WQI estimations from the study area were good and poor water with majority of them being good water (88 %). Only water from Nk-w1, Nk-w2 and Nk-site were classified poor water. The poor nature of water from the above sites, all in Nkonya, could be due to the high turbidity levels in groundwater in those areas. The turbidity of samples from Nk-w1 (25.9 NTU), Nk-w2 (25.91 NTU), and Nk-site (25.89 NTU) were above the WHO/EP-Gh guideline values. Such level of turbidity is a major public health concern which requires urgent remediation to prevent any possible adverse health effects from the use of groundwater for domestic activities. Mining activities in the study area could be a major cause of this problem since the changes in water quality resulting from mining activities include increase of water turbidity, concentrations of major ions and trace elements.

CONCLUSIONS AND RECOMMENDATIONS

This study generally revealed that acceptable levels of trace metals such as zinc, copper, manganese, and lead existed in the groundwater in the study area. However, there was high arsenic, iron and cadmium pollution in the study area which requires urgent attention due to the potential adverse human health effects associated with exposure to high levels of these metals. The study also revealed that the physicochemical properties of groundwater from the study area were within acceptable limits for potable water with the exception of pH and turbidity. Groundwater samples were very acidic in some cases and in most cases, slightly acidic yet outside the recommended range of the WHO/EPA Ghana for potable water. There was high turbidity in some groundwater samples in the study area making these groundwater sources unhealthy for domestic consumption. The majority of groundwater sources in the study were found to be good for domestic consumption. However, three of the five samples from Nkonya (Nk-w1, Nk-w2 and Nk-site) were poor for domestic consumption due to high WQI values that are suggestive of high levels of pollution giving these samples a poor classification. The classification of these water sources was mainly attributed to the high levels of turbidity in these samples. There is a strong perception among the community members that odour and salty taste are often observed in groundwater in the area despite reporting that they only used groundwater for domestic activities sometimes. The concern of saltiness was attributed to high levels of sodium from natural and anthropogenic activities (e.g., erosion of salt deposits). Also, concerns of odour were attributed to the presence of hydrogen sulfide stemming from the activities of iron and sulfur bacteria. While these concerns make groundwater unpalatable, most community members rated the quality of groundwater as acceptable. There is the need for EPA Ghana to control the levels of arsenic, iron and cadmium levels in groundwater in the study area. Anthropogenic activities known in the literature to contribute to groundwater pollution such as illegal uncontrolled mining should be tackled with the necessary urgency to limit further pollution of groundwater sources.

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