Assessment of the Potability of Underground Water from a Small Scale Underground Mine: A Case Study *

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Abstract

This study sought to investigate the potability of underground water from the Mohammed and Brothers Small Scale Underground Mine in Tarkwa by analysing two samples of the underground water to determine the water's physico-chemical parameters and the metals concentrations and coliforms in it. The physico-chemical parameters were analysed using Oyster series multi-meter (341350A) and Hydro test HT 1000 photometer. The result showed that the parameters were within the recommended World Health Organisation (WHO) and United States Environmental Protection Agency (USEPA) limits except for salinity and apparent colour. Analyses for metals and arsenic were conducted using the Varian Atomic Absorption Spectrometer (Varian ASS 240 FS). All the metals analysed were within the standards set by WHO and USEPA but the level of arsenic was above limit. The level of total coliforms and faecal coliforms were determined at the Intertek Service Limited, Tarkwa. The result showed that the levels were within the standards set by WHO and USEPA. The Water Quality Index (WQI) was calculated using the analysed water parameters. High levels of arsenic and salinity in the water renders it unsafe for drinking. Treatment of the water to reduce the arsenic and salinity levels to the standards set by WHO and USEPA will make it suitable for drinking and other domestic purposes.

Keywords: Underground Water, Small Scale Underground Mining, Water Quality, Heavy Metals, Gold

1 Introduction

The study of pure and safe drinking water has become necessary and receiving much attention by researchers in Ghana (Frimpong *et al*., 2016; Asklund and Eldvall, 2005). This is because water is one of the basic elements required for life but about 3.5 million people die as a result of water borne diseases in developing countries including Ghana due to the fact that they drink unwholesome water (Buxeda *et al*., 2003; Ewusi *et al*., 2016).. In Ghana, about 30% of the population have access to treated pipe-borne water which is safe drinking water while about 70% rely on alternative sources such as boreholes, streams, rain water and rivers (Seidu and Ewusi, 2018; Ewusi and Kuma, 2014).

The situation in Tarkwa, a mining town in the western Region of Ghana, is that there is intermittent shortage of treated pipe-borne water due to the irregular supply of water from the Bonsa Treatment Plant (Seidu and Ewusi, 2018). Even when the water is supplied, not everybody would want to access the water because they cannot afford the high water tariff. As a result, many residents depend on water from mechanised boreholes which are crowded during water shortages (Ewusi and Kuma, 2011) for supply of water. Groundwater is a good source for potable water supply but it could be contaminated by heavy metals that may have serious impacts on human health (Seidu and Ewusi, 2016; Ewusi *et al*., 2017a; Asklund and Eldvall, 2005).

Several studies attest to the fact that most of the mining activities contribute massively to the contamination and pollution of majority of water bodies within Tarkwa (Aghetara, 2012; Asklunel and Eldvall, 2005; Avotri *et al*., 2002).

The groundwater from the Mohammed and Brother Small Scale Underground Mine in Tarkwa is used for drinking and other domestic purposes by senior high school students and some community people in times of water shortage. However, very little is known about the suitability of this water as potable water and for other domestic purposes. Therefore, the aim of this present study is to investigate the potability of the underground water obtained from the mine by analysing the physico-chemical parameters of the water and the metals concentrations and coliforms in it.

1.1 Study Area

The study area (Fig. 1) is the Tarkwa area found at the mid-southern part of the Western Region of the Republic of Ghana (Asklunel and Eldvall, 2005) with geographic coordinates being longitude 1˚ 59´ 00″ W and latitude 5º 18´ 00″ N (Peprah *et al*., 2017). The area has average topographic altitude of about 78 m above Mean Sea Level (MSL) and has a total land area of about 905.2 km^2 (Boye *et al*., 2018). Geographically, the land is generally undulating with steep slopes parallel to each other and to the strike of the rocks in the north-south direction (Kortatsi, 2004). It lies within the main gold belt of the Republic of Ghana that stretches from Axim in the southwest direction, to Konongo

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in the northeast direction (Kortatsi, 2004; Asklunel and Eldvall, 2005). The Tarkwaian series and the birimain belt overlay at this region. The town is well noted for mining of precious minerals such as gold and manganese which contribute significantly to the economic development of the country (Mireku-Gyimah and Al-Hassan, 2009; Eshun and Mireku-Gyimah, 2002; Boye *et al*., 2018). It hosts five large scale mining companies and a number of small scale mining companies including the Mohammed and Brothers Small Scale Underground Mine.

2 Resources and Methods Used

2.1 Sampling

Two samples, S01 and S02, were collected from the Mohammad and Brothers Small Scale Underground Mine which is a renowned small scale mine in the study area on March 20, 2018, one in the morning at 8:20 GMT and one in the afternoon at 13:00 GMT (Table 1). The water samples were collected with 500 mL transparent plastic bottles thoroughly rinsed with the sample water before collection. Each sampling bottle was filled to the brim, leaving no space for air to prevent reaction with oxygen.

Table 1 Samples name and Description

SN	Label	Description
1	S01	Morning water sample (8:20 GMT)
2	S02	Afternoon water sample (13:00 GMT)

Samples taken were transported to the laboratory in ice packs and cooler containers to ensure a low temperature of about 4 ^{0}C to 11 ^{0}C was maintained at all times.

2.2 Sample Analyses

An Oyster series multi-meter (341350A) was used to measure the following physico-chemical parameters: pH, temperature, Oxidation-Reduction Potential (ORP), Total Dissolved Solids (TDS) and conductivity. Turbidity, colour (apparent and true) and Total Suspended Solids (TSS) were measured using a Hydro test HT 1000 photometer. The cations (Cu, Pb, Ca, Cd, K, Mg, Mn and Na) were analysed using the Varian Atomic Absorption Spectrometer (Varian ASS 240 FS) at the University of Mines and Technology (UMaT) Minerals

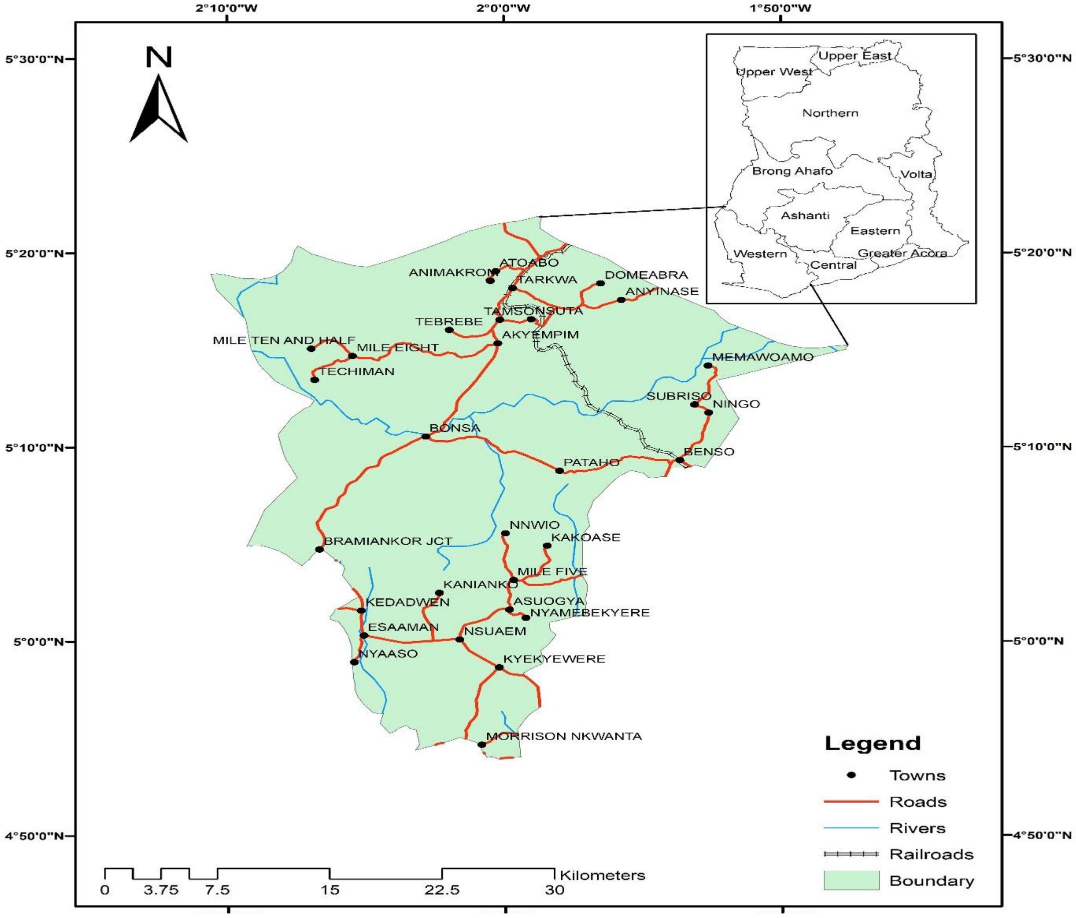

Fig 1. Map of the Study Area

Engineering Laboratory. Alkalinity (ALK), faecal coliform, Biological Oxygen Demand (BOD), Demand Oxygen (DO), total coliforms, As, Hg, HCO_3^-, Cl^-, PO_4^{3-}, SO_4^{2-} and NO_3^- were measured at the Intertek Service Limited, Tarkwa.

2.3 Water Quality Index (WQI)

There are several water quality parameters such as Weighted Arithmetic Water Quality Index (WAWQI), Canadian Counsel of Ministers of the Environment Water Quality Index (CCMEWQI), the National Sanitation Foundation Water Quality Index (NSFWQI) and the Oregon Water Quality Index (OWQI), which help to obtain a single number to characterise the overall quality of water (Tyagi *et al*, 2013). In this study, the WAWQI was used. Table 2 shows the WAWQI rating. According to Tyagi *et al* (2013), the calculated WQI is made using Equation 1:

$$WQ_i = \frac{\sum Q_i W_i}{\sum W_i} \tag{1}$$

Where: W_i is the unit weight of the i^{th} parameter and Q_i is the quality rating scale for i^{th} parameter. The quality rating scale (Qi) for each parameter is calculated by using the expression given by Equation 2 as:

$$Q_i = 100\left[\frac{V_i - V_0}{S_i - V_0}\right] \tag{2}$$

Where: V_i is the estimated concentration of i^{th} parameter in the analysed water; V_o is the ideal value of the i^{th} water quality ($V_o = 0$, except pH =7, DO = 14.6 mg/L and 0 for all other parameters) (Kumar and Dua, 2009; Amadi *et al*., 2010; Yisa and Jimoh, 2010; Srinivas *et al*., 2011; Iticescu *et al*., 2013); S_i is the recommended standard value of i^{th} parameter. The unit weight (W_i) for each water quality parameter is calculated by using Equation 3:

$$W_i = \frac{K}{S_i} \tag{3}$$

where, K is the proportionality constant. The proportionality constant can be calculated by using Equation 4 as:

$$K = 1 \Big/ \sum \left(1/S_1\right) \tag{4}$$

3 Results and Discussion

3.1 Physico-Chemical Parameters

Detailed results for all the physico-chemical parameters analysed for the two samples, S01 and S02, are represented in Table 3.

The pH values measured for S01 and S02 were 7.35 and 6.84, respectively, showing that all the samples had a pH within the acceptable region of 6.5-8.5 stipulated by the USEPA and WHO. Low pH or acidic nature of water can cause acidosis when consumed by people (Nkansah *et al*., 2010). Exposure to extreme pH values results in irritation of the eyes, skin and mucous membranes (WHO, 1996). Eye irritation and exacerbation of skin disorders have been associated with pH values greater than 11 (Anon., 1996).

Conductivity levels recorded for the samples were 351.1 uS/cm for S01 and 362.5 uS/cm for S02, which are within the acceptable limit of USEPA (<750 uS/cm) and WHO (<150 uS/cm). Conductivity of water measures the ability of water to conduct electrical current. It may be caused by the presence of certain acids or bases or the presences of ions in the water. Some ions such as Pb^{2+} and Cr^{3+} in high amount may pose health risks like respiratory problems, stomach upset, damage to the central nervous system and immune system to consumers (Oyem *et al*., 2014).

Samples S01 and S02 recorded turbidity levels of 7.85 FAU and 4.66 FAU, respectively. The turbidity level of sample S01 is above the acceptable limit of < 5 FAU set by USEPA and WHO. Turbidity is the measure of the suspended matter such as silt, clay and fine particles of organic and inorganic matter, phytoplankton and microscopic organism. High turbidity of water

Table 2 Water Quality Rating

WQI Value	Rating of Water Quality	Grading
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very poor water quality	D
Above 100	Unsuitable for drinking	E

makes the water aesthetically objectionable by consumers.

Salinity measures the salt content of water samples. The samples S01 and S02 recorded salinity of 215 and 217, respectively, which are above the set limit of 100 by WHO. There is a wealth of epidemiological proof associating high salt intake with the risk of hypertension in children and adult and also disorders in pregnancy (He and Macgregor, 2009; Duley *et al* 2005). The location of the mine falls within the Tarkwaian Series and is associated with clay minerals and elements such as sodium and calcium. The presence of these elements can contribute to increase in salinity. These elements can react with NO^{-}_{3}, SO^{2-}_{4} and Cl^{-} leading to formation of salt. Also, dissolution of clay minerals can contribute to increase in salinity. Desalination by reverse osmosis can be applied to reduce the salt level to the acceptable level or below the acceptable level.

3.2 Metals and Arsenic Analyses

Detailed results of the metals and arsenic analyses are represented in Table 4. All the metal analysed were within the standards set by USEPA and WHO with the exception of arsenic (As).

Sample S01 recorded arsenic level of 0.065 mg/L while S02 recorded 0.044 mg/L which are above the set limit of 0.01 stipulated by WHO. Arsenic exits primarily as oxy anions in groundwater, in the form As III (arsenite) and As V (arsenate) (Ferguson and Gavis,1972; Cullen and Reimer,1998). The birimian rocks contain pyrite and arsenopyrite minerals. Dissolution of these rocks introduce As into the underground water. At pH 6.5 to 8.5, As III is present as unchanged arsenious acid, H_3AsO_3, under reducing conditions. Oxidising of As III to As V enhances the formation of compound with metal cations such as Cu^{2+}, Mn^{2+}, Fe^{2+} and Ca^{2+}. The compound formed can be filtered using 0.45 µm filter therefore reducing the concentration of As to the acceptable limit. Arsenic is carcinogenic in humans if exposed orally or by inhalation (Saha *et al*., 1999). Arsenic is a protoplastic poison as a result of its effect on sulphydryl group of cells interfering with cells enzymes, cell respiration and mitosis (Gordon and Quastel, 1948). It has been reported that chronic oral exposure to inorganic arsenic of 0.05-0.1 mg/kg per day causes neurological and haematoligical toxicity in human (Byron *et al*., 1967)

3.3 Anion and Biological Analyses

Results obtained for all biological and anion analyses for the samples are presented in Table 5. The USEPA and WHO stipulated values for coliforms in water is 0/100 mL and all the samples recorded 0/100 mL faecal and total coliforms count Thus, all samples analysed recorded values that were within the acceptable standard of WHO and USEPA. All the anions measured were within the set standard by WHO.

Calculated WQI for S01 and S02 is shown in Table 6 and Table 7 respectively. The WQI for S01 is 619.94 which is above 100 making it unsuitable for drinking per the water quality. WQI for S02 is 421.19 which is lesser than that of S01 but above 100 making it unsuitable for drinking per the water quality rating. High values of WAWQI obtained

Table 3 Results of Physico-Chemical Parameters

Sample	pH	Cond	TDS	TUR D	Colour		BOD	DO	TSS	TH	ALK	Sal	ORP
Labels		uS/cm	mg/L	FAU	APP	True	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
S01	7.35	351.1	230.9	7.85	80	0	4.08	4.52	1	106	78	215	5
S02	6.84	362.5	235.6	4.66	56	0	3.12	5.21	2	86	66	217	32
MCL*	**6.5-8.5**	**1500.0**	**1000.0**	**5.0**	**15.0**	**0.0**	**-**	**-**	**20.0**	**-**	**-**	**100.0**	**650.0**

***MCL= Maximum Containment Level**

Table 4 Results of Metal Analysis

Sample	Cu	Pb	Cd	Mn	Mg	Na	K	Ca	Fe	As	Hg
Labels	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
S01	0.045	<0.002	<0.002	1.360	3.129	9.272	3.136	57.940	0.002	0.065	<0.001
S02	0.039	<0.002	<0.002	1.335	3.183	9.292	2.893	60.880	0.002	0.044	<0.001
MCL*	2.000	0.010	0.050	0.500	150.000	200.000	30.000	40.000-80.000	0.300	0.010	0.000

***MCL= Maximum Containment Level**

Table 5 Results of Anion and Biological Analyses

Sample	PO_3^{-4}	SO_2^{-4}	NO^-_3	Cl^-	HCO^-_3	Feacal Col	Total Col
Labels	mg/L	mg/L	mg/L	mg/L	mg/L	count/100mL	count/100mL
S01	0.651	5.288	0.644	4.945	54	0	0
S02	1.233	8.233	1.333	6.321	48	0	0
MCL*	2.5	400	100	250	-	0	0

***MCL= Maximum Containment Level**

Table 6 Calculation of Sub-Indices and WQI for S01

Parameters	V_i	S_i	Q_i	$1/S_i$	K	W_i	Q_iW_i
pH	7.35	8.5	23.33	0.1176	0.009448	0.001111529	0.025931981
Cond	351.1	1500	23.41	0.0007	0.009448	6.29867E-06	0.000147452
TDS	230.9	1000	23.09	0.0010	0.009448	0.000009448	0.000218154
Turbidity	7.85	5	157	0.2000	0.009448	0.0018896	0.2966672
Colour	80	15	533.33	0.0667	0.009448	0.000629867	0.335926789
TSS	1	20	5	0.0500	0.009448	0.0004724	0.002362
Mg	3.128	150	2.09	0.0067	0.009448	6.29867E-05	0.000131642
Mn	1.36	0.5	272	2.0000	0.009448	0.018896	5.139712
Na	9.272	200	4.636	0.0050	0.009448	0.00004724	0.000219005
Ca	57.94	80	72.425	0.0125	0.009448	0.0001181	0.008553393
K	3.136	30	10.45	0.0333	0.009448	0.000314933	0.003291053
Fe	0.002	0.3	0.67	3.3333	0.009448	0.031493333	0.021100533
As	0.065	0.01	650	100.00	0.009448	0.9448	614.12
Cl^-	4.945	250	1.978	0.0040	0.009448	0.000037792	7.47526E-05
NO_3^-	0.644	100	0.644	0.0100	0.009448	0.00009448	6.08451E-05
SO^{2-}_4	5.288	400	1.322	0.0025	0.009448	0.00002362	3.12256E-05
				105.8433		1.000007628	619.954428
WQI=619.949699							

Table 7 Calculation of Sub-Indices and WQI for S02

Parameters	V_i	S_i	Q_i	$1/S_i$	K	W_i	Q_iW_i
pH	6.84	8.5	-10.67	0.1176	0.009448	0.001111529	-0.01186001
Cond	362.5	1500	24.17	0.0007	0.009448	6.29867E-06	0.000152239
TDS	235.6	1000	23.56	0.0010	0.009448	0.000009448	0.000222595
Turbidity	4.66	5	93.20	0.2000	0.009448	0.0018896	0.17611072
Colour	56	15	373.33	0.0667	0.009448	0.000629867	0.235148123
TSS	2	20	10	0.0500	0.009448	0.0004724	0.004724
Mg	3.183	150	2.122	0.0067	0.009448	6.29867E-05	0.000133658
Mn	1.335	0.5	267	2.0000	0.009448	0.018896	5.045232
Na	9.292	200	4.646	0.0050	0.009448	0.00004724	0.000219477
Ca	60.88	80	76.1	0.0125	0.009448	0.0001181	0.00898741
K	2.893	30	9.64	0.0333	0.009448	0.000314933	0.003035957
Fe	0.002	0.3	0.67	3.3333	0.009448	0.031493333	0.021100533
As	0.044	0.01	440	100.00	0.009448	0.9448	415.712
Cl^-	6.321	250	2.5284	0.0040	0.009448	0.000037792	9.55533E-05
NO_3^-	1.333	100	1.333	0.0100	0.009448	0.00009448	0.000125942
SO^{2-}_4	8.233	400	2.058	0.0025	0.009448	0.00002362	4.861E-05
				105.8433		1.000007628	421.1954768
WQI=421.1922639							

for the samples both S01 and S02 were as a result of high concentrations of arsenic in both samples. If arsenic levels in the water is reduced to the set standard, the recalculated WQI for S01 and S02 would be 5.83 and 5.48, respectively. The treatment of the water to reduce the arsenic level will make it safe for drinking and other domestic purposes.

4 Conclusion

The objective of the study was to assess the quality of the underground water from the Mohammed and Brothers Small Scale Underground Mine. This was to determine if it could serve as an alternative source of drinking water and for other domestic purposes for the nearby communities. The results of the study revealed high level of arsenic and salinity making it unsafe to drink. Treatment of the water to reduce the arsenic and salinity levels to the standards set by WHO and USEPA will make it suitable for drinking and other domestic purposes. A batch treatment system using reverse osmosis filters and distillation can be used to reduce As and salinity level to the acceptable limits. Alternatively, a combination of alum, ferric chloride and ferric sulphate can be used as a coagulant to remove As.

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