Estimation of Risk Levels of Water-Quality Parameters in Groundwater in a Local Community of Ghana

Simon K. Appiah[1]*, Joseph Apau[2], A. Andoh[2], D. Armah[2], G. Yeboah[2]

[1]Department of Mathematics, College of Science, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

[2]Department of Chemistry, College of Science, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Abstract Groundwater is a natural source of drinking water for several communities in Ghana. However, there are various natural and anthropogenic activities carried out, which often release risk substances to the environment. These pose serious threat to the water from this valuable natural resource, hence the urgent need for regular monitoring to ascertain its quality. In this study, water quality analysis is conducted to determine the risk levels of heavy metals and physio-chemical properties using groundwater from Tarkwa-Nsuaem Municipality, a vulnerable mining community in the Western Region of Ghana. Water samples were collected from existing boreholes or wells, randomly selected from various towns and villages within the Municipality. The samples were analysed for the contamination levels using standard procedures and results compared with the World Health Organization (WHO) recommended guidelines for water-quality. The results showed varying levels of risk with low exposure of arsenic (<0.009 mg/L) and trace metals contaminations of groundwater. The mean concentration levels of manganese (0.14-4.85 mg/L) and iron (0.09-1.48 mg/L) exceeded the permissible values for 50% of the samples while the physio-chemical parameters observed were pH, total hardness, total dissolved solids, alkalinity and electrical conductivity. The mean pH levels of the samples were mostly acidic (3.50-7.51) and also fell below the permissible values of 6.5-8.5 while 30% of the samples contained nitrate concentrations which exceeded the permissible value of 50 mg/L. Generally, the groundwater in the Municipality area was found safe for drinking or domestic purposes. However, the few elevated cases of contaminations need urgent attention for remedial action to be taken to prevent further pollution and any health related problems.

Keywords Tarkwa-Nsuaem Municipality, groundwater, water quality, arsenic and heavy metals risk, physio-chemical parameters

1. Introduction

Water resources such as streams, rivers, lakes, dams, waterfalls, underground and rain water abound in Ghana. However, the major concern has been how to make these resources safe for human consumption as they are often polluted by the natural and anthropogenic activities carried out in such environments. Water pollution threatens development projects, agriculture, industry and even human existence and makes water treatment essential in order to become safe for drinking. It has been clearly demonstrated that good quality water is crucial to sustainable socio-economic development [1-3]. The problems related to water quality deterioration have been in existence for a long time but have recently reached a critical dimension, while the newly emerging ones are alarming. Direct contamination of groundwater from pollutants of mining, smelting and industrial manufacturing is a long standing phenomenon, which is susceptible to leaching from waste dumps,

mine tailings and industrial production sites [3-4]. Arsenic is a naturally occurring element which is widely distributed in the earth's crust; it can be found in food, soil, air, and water and all human populations are exposed to it in one form or another. It is mostly obtained as a by-product of processing minerals such as gold, silver, copper, and other metal ores and it has been known since antiquity in sulphide compounds. Sulphide minerals can form soils with very high concentration of arsenic, which can dissolve in water [5-7]. Since valuable other heavy metals such as copper (Cu) and gold (Au) can also be found in sulphide mineral deposits, mining exploration companies will often look for soil and water bodies with a naturally high arsenic content as a means of locating an ore body. Arsenic (As) contamination of groundwater is known to cause severe health problems in several developing countries. It is mobilized into the environment and enters drinking water supplies through volcanic emission as well as through a range of anthropogenic activities [8-9, 6].

There are two forms of arsenic compounds, organic and inorganic; water contains primarily the inorganic forms of arsenic, which is more toxic and often associated with long-term health effects [10-12]. In groundwater, arsenic chiefly occurs as inorganic oxyanions of arsenite [As(III)] and arsenate [As(V)], although under specific conditions, methylated and other organo-arsenicals species may occur as either $H_2AsO_4^-$ or $HAsO_4^{2-}$, whereas in more reducing environments, As(III) predominates and is present as H_3AsO_3. Fortunately, As(III) can be easily oxidized to As(V) by strong oxidants such as chlorine, ozone, and potassium permanganate [13-17].

Generally, some of the pertinent environmental issues pertaining to mining include erosion and sediment control, water conservation and balance, fugitive dust control, hydrocarbon or chemical spill control, waste streams or hazardous substances control, air pollution and mine tailings containment. The problems of water management in Ghana are mostly attributed to the lack of accurate and reliable database on the water resources [18, 1, 3]. Organizations such as the World Health Organization (WHO) and Environmental Protection Agency (EPA) of Ghana have established specific permissible or tolerable levels of chemical pollutants allowable in water bodies. The Tarkwa-Nsuaem Municipality gets its treated water supply from Bonsaso but most of the time, there is shortage of water supply from this source and most communities in the Municipality therefore rely frequently on groundwater (boreholes or dug wells) for drinking and other domestic activities. However, the intense mining activities engaged in the area degrade the natural environment, destroy the ecosystem, and eventually pollute the water bodies. Often, drinking water from such natural sources including underground are untreated or analyzed for safe consumption, which poses some potentially health risk problems to vulnerable communities [19]. This study seeks to determine the concentration levels of arsenic and other amount of heavy metals (iron, and zinc, cadmium, manganese and copper) as well as to conduct physio-chemical studies on the groundwater in this local community in western part of Ghana.

2. Materials and Methods
2.1. Study Area
Tarkwa-Nsuaem Municipality is one of the twenty two (22) administrative metropolitan, municipal and district assemblies in Western Region of Ghana [19]. The Municipality is located between latitudes 4°N and 5°40' and longitudes 1°45'W and 2°10'W and bounded to its north is Prestea Huni-Valley District, the south by the Ahanta West District, the west by the Nzema East Municipal and the east by the Mpohor Wassa East. It has a total land area of about 978 km^2 and found within the forest- dissected plateau with heights ranging 240–300 metres above sea level. The area is part of the Precambrian rocks of Birimian and Tarkwaian geological formations with high potential of mineral deposits. The Municipal is predominantly agricultural and mining region and has capital town called Tarkwa, which is well-known of gold and manganese mining activities. The mining operations are usually carried out by large and small scale mining companies. Ghana Manganese Company Limited (GMCL), Goldfields Ghana Limited (GFGL), and AngloGold Ashanti are some of the large scale mining companies that can be found in Tarkwa and its surrounding towns. The Tarkwa-Nsuaem Municipal has a mean annual rainfall of 187.83 cm with a double maximum rainfall starting from March to September as the main rainfall (or wet) season and October to February as the dry season [19-21]. Figure 1 shows map of Tarkwa-Nsuaem Municipality and the sampled locations of the data collection of water samples.
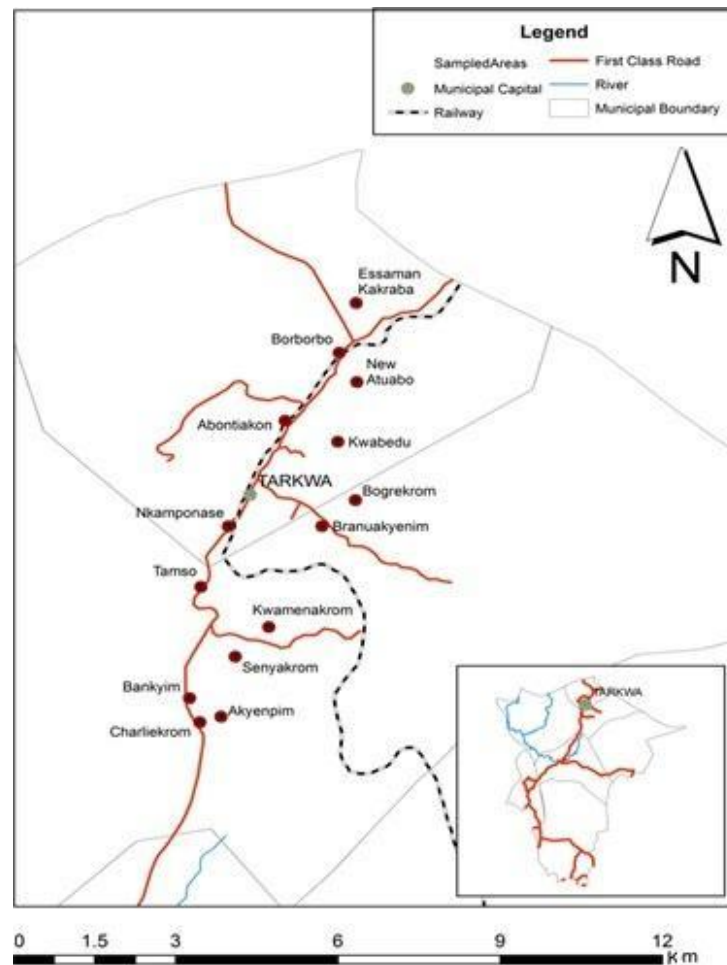
Figure 1: Map of Tarkwa-Nsuaem Municipality showing the sampled locations of the underground water

2.2. Sampling

The treatment of high density 500 mL plastic containers was done by washing them with acetone to get rid of any organic contaminants such as grease and fat residues. They were rinsed using deionized water before being soaked in 0.1 M nitric acid solution for 48 hours. The containers were rinsed with deionized water and dried in an oven for a few minutes to avoid contamination. The cleaned 500 mL high density plastic bottles were used to collect water at the sampling sites. The water samples were taken from wells and boreholes at the various households used for domestic purposes. Before sampling, the boreholes were pumped for about ten minutes before samples were taken. This was done in order to avoid sampling of stagnant annulus water that would be in the region of pump and pump systems. The water from the wells and boreholes were collected from bowls or containers that the communities used to fetch the water from them.

2.3. Experiments

In the determination of pH, conductivity and total dissolved solids (TDS), a Horiba U51 water quality multimeter was used. Fifty (50) ml of each of the water sample was put in a clean 100 ml beaker and the multimeter was immersed in it and the readings were recorded. Total alkalinity was determined by titrimetric method using 0.1 N sulphuric acid as titrant and methyl orange as indicator. Using pipette, 50 ml of each water sample was measured into a clean conical flask and two drops of methyl orange indicator was added. A yellow solution was formed which was then titrated against 0.1 N H_2SO_4 to a pale pink end point. EDTA titrimetric method was used to determine the total hardness of the water samples. Fifty (50) ml of each water sample was pipetted into a conical flask and buffered to a pH of 10 and few drops of Eriochrome Black-T was added. The

content of the conical flask was titrated with 0.01 M standard EDTA solution, which was then swirled until the colour changed from violet to blue. Ion exchange chromatography (IEC) was used to determine the concentration of ions. Ten (10) ml of each water sample was filtered to get rid of particles that may clog the column. The mobile phase used for the cation was nitric acid of 800 mg/L and that of the anion was sodium hydrogen carbonate of 84 mg/L. Cation and anion standards, 10 ppm, 20 ppm, 30 ppm, 40 ppm and 50 ppm were used for calibration. The standards were run first before that of the samples.

The heavy metals digestion and its determination was performed by adding to 50 ml of each of the water sample, 10 ml 60% (v/v) nitric acid and evaporated to half of its volume using a hot plate. The resulting mixture was cooled and filtered into 50 ml volumetric flask using the 45 µm filter paper and topped to the mark. The concentrations of the heavy metals were then determined using the Atomic Absorption Spectrometer (AAS), first proposed by Walsh [22] for performing such chemical analysis [23]. The total dissolved arsenic was determined by adding 1.5 ml of concentrated hydrochloric acid to 100 ml of the previously filtered (0.45 μm pore size membrane) water sample. One (1) gram of potassium iodide (KI) was added to each sample to reduce the As(V) to As(III) which is a form detectable by the AAS. To ensure reproducibility and quality assurance, all analysis were done in replicates.

3. Results and Discussion

Samples of the groundwater from the selected communities within the Tarkwa-Nuaem Municipality in Western Region of Ghana were collected over a period of three months for each community. The water quality analysis of the samples from the communities included determination of levels of arsenic contamination (total and dissolved), physiochemical parameters (pH, total hardness, total dissolved solids, alkalinity and electrical conductivity) and concentration of other heavy metals mainly, Cu, Fe, Mn, Ca and Zn. The results of the analysis of the water samples are presented in Tables 1-5 and compared with the World Health Organization (WHO) limit guidelines for drinking water [24-26] since the communities within the study areas, like most other areas in the country, use the untreated water for domestic purposes.

3.1. Arsenic Contamination Levels

Tables 1–2 show the results for the arsenic concentrations for the dissolved and total measurements, respectively for the samples. All the 20 samples analyzed for dissolved arsenic contamination in January and March were all found below the detection limit of 0.001 (see Table 1). However, in February, only 45% of the samples were found below the detection limit of dissolved arsenic with samples BAN, CHA, BRA 2 and BAM recording concentration levels of 0.002 mg/L each. These observed values were also below the WHO limit guideline of 0.01mg/L and so did not pose serious health problem. Samples AKY, BOB, BRA1, AKE and BOG gave dissolved arsenic values of 0.003 mg/L while sample ABO gave the highest arsenic value of 0.005 mg/L.

The total arsenic concentration in the month of January for all the samples gave concentration values that were below detection limit except sample AKE which recorded a value of 0.003 mg/L. In February most of the samples showed increase in concentration total of arsenic with observed samples BAN, AKY, CHA, BRA1, BRA2, COM and BAM recording total arsenic concentration of 0.003 mg/L or 0.004 mg/L. Total arsenic concentration of 0.005 mg/L was recorded in samples BOB, AKE and BOG while BAN and ABO samples gave concentrations 0.006 and 0.008 mg/L, respectively (see Table 2). The values recorded for 49% of the samples fell below the detection limit of 0.001. Only sample AKE recorded the highest total arsenic concentration value of 0.002 mg/L in March, which is also below the WHO limit guideline value. In this month, 95% of the samples gave values that fell below the detection limit. The total arsenic concentrations measured for sample AKE range from 0.002 to 0.005 with a mean of 0.0033 and standard deviation (SD) and standard error (SE) of 0.0015 and 0.0011, respectively. All the samples analyzed were found safe for domestic use, by the WHO recommended drinking water value of 0.01 mg/L. Those samples with values below the detection limit do not necessarily mean that the arsenic is not present. There could be small presence of arsenic but cannot be reliably detected with the laboratory equipment used. However, this contaminant does not pose a health threat as the concentration levels falls below 0.001 mg/L.

Table 1: Dissolved arsenic contamination values measured in the water samples

Sample ID	January	February	March	Mean	Standard Deviation	Standard Error	Minimum	Maximum
TEB	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
BAN	<0.001	0.002	<0.001	<0.001	N/D	N/D	N/D	N/D
AKY	<0.001	0.003	<0.001	<0.001	N/D	N/D	N/D	N/D
CHA	<0.001	0.002	<0.001	<0.001	N/D	N/D	N/D	N/D
NSU	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
TAM	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
SEN	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
KWK	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
BOB	<0.001	0.003	<0.001	<0.001	N/D	N/D	N/D	N/D
BRA1	<0.001	0.003	<0.001	<0.001	N/D	N/D	N/D	N/D
TKW	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
NAT	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
AKE	<0.001	0.003	<0.001	<0.001	N/D	N/D	N/D	N/D
ABO	<0.001	0.005	<0.001	<0.001	N/D	N/D	N/D	N/D
BRA2	<0.001	0.002	<0.001	<0.001	N/D	N/D	N/D	N/D
EFU	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
BOG	<0.001	0.003	<0.001	<0.001	N/D	N/D	N/D	N/D
COM	<0.001	0.002	<0.001	<0.001	N/D	N/D	N/D	N/D
KWA	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
BAM	<0.001	0.002	<0.001	<0.001	N/D	N/D	N/D	N/D

Table 2: Total arsenic contamination values in the water samples

Sample ID	January	February	March	Mean	Standard Deviation	Standard Error	Minimum	Maximum
TEB	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
BAN	<0.001	0.006	<0.001	<0.001	N/D	N/D	N/D	N/D
AKY	<0.001	0.004	<0.001	<0.001	N/D	N/D	N/D	N/D
CHA	<0.001	0.003	<0.001	<0.001	N/D	N/D	N/D	N/D
NSU	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
TAM	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
SEN	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
KWK	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
BOB	<0.001	0.005	<0.001	<0.001	N/D	N/D	N/D	N/D
BRA1	<0.001	0.004	<0.001	<0.001	N/D	N/D	N/D	N/D
TKW	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
NAT	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
AKE	0.003	0.005	0.002	0.0033	0.0015	0.0011	0.002	0.005
ABO	<0.001	0.008	<0.001	<0.001	N/D	N/D	N/D	N/D
BRA2	<0.001	0.003	<0.001	<0.001	N/D	N/D	N/D	N/D
EFU	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
BOG	<0.001	0.005	<0.001	<0.001	N/D	N/D	N/D	N/D
COM	<0.001	0.003	<0.001	<0.001	N/D	N/D	N/D	N/D
KWA	<0.001	<0.001	<0.001	<0.001	N/D	N/D	N/D	N/D
BAM	<0.001	0.004	<0.001	<0.001	N/D	N/D	N/D	N/D

3.2. Physico-chemical Properties

Table 3 shows the five physio-chemical parameters (pH, hardness, total dissolved solids (TDs), alkalinity and electrical conductivity) and their concentration values observed in the water samples. For human beings, a pH value of 7.0 is considered as an ideal, although a range of 6.5-8.5 is permissible (WHO, 2004, 2009 [24-25]). The pH levels of the groundwater sampled from the local communities within the Tarkwa Municipality for the three months varied between 3.50 and 7.48 with sample BOB recording the lowest mean pH value of 3.69 while sample NSU had the highest mean pH of 7.08. The mean pH values of most of the water samples were below 6.50. This implies that, these water samples were acidic. The pH of samples AKY (6.58) and NSU (7.08) were the only values found within the WHO limit guideline value. The low pH of the water samples is likely traceable to the high presence of the carbonates due to the rocky nature of the study area (GSS, 2014 [21]). The alkalinity concentration levels of the groundwater sampled varied within 10–400 mg/L CaCO3. The highest mean alkalinity concentration of 326.67 mg/L CaCO3 occurred with sample COM while sample BOB had the lowest mean of 14.33 mg/L

CaCO3. All the mean values recorded were within the WHO's recommended permissible limit of 500 mg/L CaCO3, which is an indication that there is no serious health risks associated with consumption of water that is slightly acidic or basic. Water meant for human consumption should have total dissolved solids (TDS) content not exceeding 1000 mg/L (WHO, 2004, 2009, 2011 [24-26]). All the samples examined in this study were below the WHO's limit guidelines for drinking water-quality, with the majority (85%) of them falling below 500 mg/L. The mean TDS of the samples range from 31.33 mg/L to 822.00 mg/L with the highest value being recorded in sample TAM whilst the lowest value was recorded in sample SEN. The TDS values of all the samples were within the maximum allowable limit of 1000 mg/L, thus, most of the wells' water in the Municipality area were safe for drinking as far as the total solids content is concerned.

The electrical conductivity levels range from 43.30 to 1,590 µs/cm. The highest (1,529.77µ s/cm) and lowest (56.43 µs/cm) mean conductivity values were observed in samples TAM and SEN, respectively. The mean conductivity values recorded for the samples were comparatively lower and negligible per the WHO limit guideline value of 1,500 µs/cm, except for the samples of TAM which recorded the highest mean value. The low conductivity of the other 19 samples could be ascribed to natural occurrences which introduced inorganic substances into the water but most of these minerals and metallic ions, bicarbonate and chloride ions might have precipitated out causing some of the ions to settle out of the water due to adsorption resulting in the low conductivities (Järup, (2003; Kumar, et al., 2016 [27-28]). Water hardness is one of the very important properties of groundwater from utility point of view, particularly for domestic purposes. WHO (2004, 2009, 2011 [24-26]) specified a maximum guideline value of 400 mg/L of total hardness for water meant for human consumption and in this study, no sample exceeded this maximum limit. The total hardness concentration of all the samples within the study area varied between 9.76 mg/L and 289.75 mg/L CaCO3. The minimum mean total hardness concentration value occurred in sample SEN and the maximum in sample COM. It is well known that hardness is not caused by a single substance but by a variety of dissolved polyvalent metallic ions, predominantly the calcium and magnesium cations, although other cations like iron, manganese, and zinc also contribute to hardness in water (IARC, 2012, Kumar, et al., 2016 [12, 28]).

Table 3: Concentrations of physio-chemical parameters for the water samples

Sample ID	pH (Mean±SD)	Hardness/mg/ L (Mean±SD)	TDS (Mean±SD)	Alkalinity/mg/ L (Mean±SD)	Conductivity/µs /cm (Mean±SD)
TEB	5.82± 0.30	42.96±7.020	196.00±12.17	28.33±15.28	333.50±30.280
BAN	6.30±0.43	84.30±6.560	213.33±49.33	100±82.3100	363.10±119.62
AKY	6.58±0.19	199.10±16.93	720.33±27.03	180±30.4100	1235.23±56.16
CHA	5.72±0.03	43.94±1.610	106.00±6.930	48.33±2.880	182.06±22.950
NSU	7.08±0.43	166.99±10.35	307.67±16.62	183.33±17.59	529.57±20.650
TAM	5.63±0.15	237.08±8.000	822.00±53.03	45.00±5.000	1529.76±53.18
SEN	5.13±0.16	27.40±18.600	31.33±8.0900	18.33±2.880	56.43±13.3600
KWK	5.36±0.26	60.74±24.470	155.66±12.50	25.00±5.000	303.00±24.640

BOB	3.69±0.17	74.90±8.1000	436.00±5.290	14.33±7.510	748.53±55.410
BRA1	6.04±0.46	48.33±13.180	134.67±5.030	50.00±8.660	240.20±26.110
TKW	4.46±0.23	155.93±46.85	405.33±39.31	16.67±5.770	706.97±66.470
NAT	5.44±0.30	43.16±11.500	116.00±6.930	63.33±23.63	204.10±29.290
AKE	6.48±0.30	160.18±21.03	228.33±27.54	180.00±30.41	401.03±58.460
ABO	6.09±0.11	157.78±14.40	295.33±15.01	66.67±52.04	512.03±52.980
BRA2	5.04±0.26	32.71±9.3000	66.67±11.550	26.67±5.770	127.30±11.040
EFU	5.85±0.13	64.60±24.700	251.00±20.07	26.60±2.890	336.43±43.830
BOG	5.03±0.05	23.87±4.6800	93.67±10.970	18.33±7.640	173.36±40.360
COM	6.46±0.15	250.51±22.10	622.33±32.80	326.67±66.58	962.06±253.06
KWA	5.96±0.91	59.78±22.070	197.67±46.11	20.00±5.000	351.67±106.10
BAM	4.71±0.46	167.99±24.54	516.67±58.59	18.33±5.770	864.76±40.340

3.3. Heavy Metals

The study analyzed other trace metals namely, copper (Cu), iron (Fe), manganese (Mn), cadmium (Cd), and zinc (Zn) and compared with the WHO maximum limits for these heavy metals being 2.0, 0.3, 0.5, 0.003 and 3.0 mg/L, respectively (WHO, 2004, 2009, 2011 [24-26]). The samples concentration values for the heavy metals are presented in Table 4.

The Cu concentrations ranged between <0.005 mg/L and 0.154 mg/L with the highest mean value of 0.116 mg/L found in sample NZL and the lowest mean value of 0.016 mg/L in sample NSU. The mean Cu concentrations for the 10 the samples were below the WHO detection limit and recommended values of <0.1 µg/L and 2.0 mg/L, respectively. The Fe concentrations in all the water samples were mostly high, ranging from <0.01 to 3.262 mg/L. The highest mean Fe concentration occurred in sample AKY and the lowest in sample AKE. Out of the 20 samples, 9 had mean iron concentration values which fell below the WHO maximum limit value of 0.3 mg/L while the remaining 11 mean sample concentrations far exceeded the WHO guideline value. It is thus inferred that the iron content in the water samples is maximally present in the soil in those communities. Iron in the water can be associated with a bitter/metallic taste, formation of sediment and yellow, red, and orange films, and discolored clothing during washing (Kumar, et al., 2016; WHO, 2009 [25, 28]). The Mn concentrations for the samples range between 0.031 and 8.158 mg/L with the highest mean concentration of 4.85 mg/L recorded in sample NAT and the lowest of 0.14 mg/L recorded in CHA. The other 10 higher values, above the permissible value of 0.5 mg/L, were recorded at sample locations including BAN, BOB, NZL, ABO and BAM, which raise great concerns to the resident communities. Although, manganese is an essential element, the chronic ingestion of it in drinking water can be associated with neurological damage (Kondakis, et al., 1989; WHO, 2011 [26, 29]). The Zn concentrations range from <0.01 mg/L to 0.906 mg/L with the highest mean concentration (0.31 mg/L) occurring in sample EFU while the lowest mean value (0.005 mg/L) was observed in sample AKE. None of the samples exceeded the WHO maximum limit of 3.0 mg/L. The permissible level of Cd in drinking water is 0.003 mg/L (WHO, 2009, [25]) but for all the 20 samples studied for the three-month period, the cadmium concentrations obtained were all below the detection limit.

Table 4: Concentrations of heavy metals in the water samples

Sample ID	Iron/mg/L (Mean±SD)	Zinc/mg/L (Mean±SD)	Copper/mg/L (Mean±SD)	Manganese/mg/L (Mean±SD)	Cadmium/mg/L (Mean±SD)
TEB	0.41±0.41	0.02±0.00	0.020±0.00	0.22±0.22	<0.005
BAN	0.35±0.41	0.04±0.00	N/D	0.90±1.37	<0.005
AKY	1.48±1.54	0.01±0.00	N/D	0.43±0.19	<0.001
CHA	0.55±0.46	ND	0.020±0.01	0.14±0.03	<0.005
NSU	0.32±0.04	0.02±0.00	0.016±0.02	0.76±0.65	<0.005
TAM	0.13±0.07	0.05±0.06	0.070±0.07	0.61±0.46	<0.005

SEN	0.18±0.24	0.10±0.12	N/D	0.24±0.23	<0.001
KWK	0.41±0.37	0.01±0.01	N/D	0.76±0.29	<0.001
BOB	0.22±0.26	0.04±0.05	N/D	2.89±2.17	<0.005
BRA1	0.68±0.99	0.02±0.00	0.010±0.01	0.18±0.05	<0.001
NZL	0.19±0.21	0.12±0.05	0.116±0.05	1.26±0.66	<0.001
NAT	0.17±0.12	0.06±0.03	0.040±0.01	4.85±3.67	<0.001
AKE	0.09±0.06	0.005±0.0	N/D	0.41±0.31	<0.001
ABO	0.42±0.50	ND	0.030±0.02	1.06±0.56	<0.001
BRA2	0.19±0.22	ND	N/D	0.29±0.26	<0.001
EFU	0.39±0.28	0.31±0.52	0.020±0.02	0.77±0.44	<0.005
BOG	0.15±0.13	0.01±0.00	N/D	0.26±0.07	<0.001
COM	0.88±0.58	0.02±0.01	N/D	0.42±0.09	<0.001
KWA	0.46±0.66	0.02±0.01	N/D	0.55±0.27	<0.001
BAM	0.27±0.21	0.03±0.02	0.020±0.02	1.28±0.82	<0.005

In the case of the concentration ions observed in the water samples (see Table 5), magnesium and calcium ions were remarkably of low values. The mean magnesium ion levels in the samples range between 23.9004 and 113.7032 mg/L with the highest mean value measured in sample TAM whilst the lowest mean value was recorded in sample SEN. The mean calcium ion concentration in the samples range from 1.15 to12.82 mg/L with sample COM recording the highest mean value whilst the lowest mean value was recorded in sample SEN. These values were below the maximum guidelines given by WHO (2004, 2009, 2011 [24-26]). These comparatively low values for these cations definitely contributed to the low values measured for the total hardness in the water samples.

The fluoride levels range from 0.1623 to 1.9825 mg/L. The highest (1.524 mg/L) and lowest (0.445 mg/L) mean values were recorded in samples NZL and BOB, respectively. The WHO guideline limit value for fluoride is 4 mg/L, but because of the potential for dental fluorosis (mottled or discolored teeth), the Ghana EPA has set a secondary standard of 2 mg/L. This value was not exceeded by any of the samples obtained. Fluoride was also not indicated in 11 samples in January and in 6 samples in February. Elevated levels of fluoride have been shown to cause bone disease while low levels of fluoride may help to prevent cavities in teeth (Amfield, 2005, 2008; Bassin, et al., 2006; Blakey, et al., 2014 [30-33]).

The chloride levels for all the 20 samples during the three-month period range 1.98–200.89 mg/L which did not exceed the WHO limit guideline value of 250 mg/L. The highest (204.12 mg/L) and lowest (16.83 mg/L) mean values were recorded in samples TAM and SEN, respectively. From these results, there appears to be fewer natural sources of chlorides likely to pollute the groundwater in the area under study. Elevated levels of chloride can also be associated with septic system effluent, brine water, cleaning solutions, and other industrial solutions. The standard value is set for safe consumption of chlorides because of these potential aesthetic problems associated with the taste of the water (Stoddard, et al., 2005 [34]).

Sulphate ions were tested and found to have the high mean values of 114.5168 mg/L and 65.14 mg/L in samples TAM and BAM, respectively and low values of 3.72 mg/L and 4.7 mg/L in samples SEN and BAN, respectively. However, the actual measured sulphate concentrations range from 3.89 to 126.32 mg/L for the three-month period. These values were far below the WHO limit guideline for sulphate of 500 mg/L, an indication of low risk of presence of sulphate concentrations in the groundwater of the communities in the study area. However, at a level of 250 mg/L, sulphate can impart a bitter to salty taste to the water and also contribute to corrosion of distribution systems while a level of over 500 mg/L can result to a laxative effect (WHO, 2004, 2009 [24-25]).

Sodium and potassium ions were found in all the samples except in NZL, which did not detect Na ions. Like the sulphate ions, high mean concentrations of Na and K were associated with samples TAM, AKY, BAM and COM while extremely low mean values were detected in samples SEN, AKE, CHA and BRA2. The highest mean values of Na (174.33 mg/L) and K (44.78 mg/L) were recorded in TAM and AKY, respectively while

the lowest values of Na (6.67 mg/L) and K (0.36 mg/K) were both observed in SEN. All the observed concentration levels of Na and K were well within the permissible limits of 200 mg/L and 50 mg/L, respectively as set by (WHO, (2004 [24-26]).

The concentrations of nitrate ions in the samples of the groundwater in the study area range from 2.05 mg/L (in AKE) to 190.95 mg/L (in TAM) over the three-month period (see Table 5). The highest and lowest mean values recorded were 188.14 mg/L and 5.76 mg/L in TAM and SEN, respectively. It is observed that the WHO limit guideline is exceeded only by 30% of the water samples. Water which has zero nitrates hardly occurs in nature and so an upper limit of 50 mg/L of nitrates is set for water meant for domestic consumption (WHO, 2004, 2009, 2011 [24-26]). Therefore presence of nitrates in groundwater in domestic settings is one of the indicators of contact with human wastes. Also, the use of highly soluble fertilizers which contain nitrates causes water pollution problems as rainwater leaches out these nitrates and carries them into nearby streams while some portion infiltrates into the ground (Stoddard, et al., 2005 [34]). Various health concerns have been expressed regarding the issue of drinking water containing high levels of nitrates (L'hirondel and L'hirondel, 2002; Powlson, et al., 2008; Ward et al., 2005, 2006; WHO, 2004 [35-38, 24]).

4. Conclusion

Groundwater samples were analyzed for various heavy metals contamination and physio-chemical parameters and the results compared with standard values recommended the WHO (WHO, 2004, 2009, 2011) and Ghana's EPA guidelines for drinking water-quality. The arsenic concentrations in the groundwater sampled from the communities for the study were found below the WHO permissible guideline values. Most of the physio-chemical parameters considered were also within the WHO recommended limits. The pH levels in the samples were generally acidic and most cations and anions tested fell within the maximum acceptable range. Thirty (30) percent of the samples contained nitrate concentrations exceeding 50 mg/L with elevated concentrations occurring in groundwater samples collected at TAM. For the five heavy metals analyzed, manganese and iron exceeded the WHO permissible guideline value. Generally, most of the wells did not have any readily noticeable source of contamination in their environments and can therefore be concluded, per the findings herein, that the groundwater in the Municipality is safe for drinking and/or domestic purposes. However, the groundwater in a few sampling sites, are not suitable for domestic purpose and urgent remedial action ought to be taken to prevent related health problems in future.

Table 5: Concentration levels of ions observed in the water samples

Sample ID	Chloride/mL (mean± SD)	Fluoride/mg/L (mean± SD	Sulphate/mg/L (mean±SD)	Nitrate/mg/L (mean± SD)	Sodium/mg/L (mean± SD)	Calcium/mg/L (mean± D)	Magnesium/mg/L (mean± SD)	Potassium/mg/L (mean± SD)
TEB	54.12±8.26	0.62±0.19	-	30.87±4.87	38.45±6.23	3.44±0.01	38.34±5.40	1.53±0.10
BAN	47.26±38.80	1.35±0.56	4.270±0.54	-	29.52±8.28	6.37±0.45	42.99±5.93	0.90±0.36
AKY	151.47±15.32	-	57.19±7.93	93.85±11.51	126.21±12.39	8.04±0.93	99.13±16.42	44.78±3.10
CHA	26.51±2.05	-	6.760±0.95	10.23±4.66	13.57±0.49	2.11±0.00	38.63±0.74	1.09±0.05
NSU	48.85±1.04	-	26.36±1.36	-	30.34±0.40	7.17±0.94	76.65±4.15	0.67±0.09
TAM	204.12±4.57	0.53±0.24	114.51±16.69	188.14±3.97	174.33±6.81	10.76±0.62	113.70±3.83	33.24±1.59
SEN	16.83±4.00	-	3.720±0.26	5.76±1.56	6.67±0.09	1.15±0.13	23.90±1.11	0.36±0.19
KWK	42.04±0.44	-	25.35±0.87	7.37±2.76	29.09±1.35	2.57±0.03	32.08±4.44	2.49±0.07
BOB	66.83±91.72	0.45±0.40	16.50±1.14	81.77±1.31	94.40±4.77	5.55±0.19	47.59±3.29	12.98±0.91
BRA1	39.36±5.36		9.310±2.67	8.09±1.43	24.20±0.50	3.09±0.22	42.59±0.08	2.40±0.18
NZL	107.62±0.28	1.52±0.65	29.85±1.94	109.9±3.85	-	3.99±0.38	77.04±3.79	15.91±0.27
NAT	38.65±4.92	-	5.49±0.99	7.38±0.52	20.95±0.50	5.84±0.67	39.16±0.63	0.94±0.09
AKE	19.27±5.28	-	7.110±2.26	-	18.29±4.25	7.64±0.13	67.58±1.36	0.56±0.26
ABO	69.30±15.53	0.54±0.41	13.51±2.96	22.03±1.29	38.40±10.07	7.39±6.21	73.13±4.11	1.24±0.16
BRA2	27.00±5.22	-	4.390±0.57	10.54±3.40	14.31±2.32	8.91±9.97	30.39±1.59	0.84±0.20
EFU	51.74±1.18	-	27.28±0.30	58.59±13.29	35.81±0.43	5.54±0.59	49.84±0.55	13.41±5.67
BOG	29.30±0.32	-	5.880±0.57	15.99±1.57	20.63±1.08	2.05±0.12	31.59±1.39	1.66±0.16
COM	124.81±15.26	-	38.07±6.85	42.46±7.64	87.48±2.07	12.82±0.97	102.04±0.49	39.96±3.53
KWA	59.01±39.55	0.59±0.07	13.53±2.84	24.59±25.79	39.70±53.65	2.86±0.39	42.33±9.66	6.17±3.53
BAM	171.63±8.15	-	65.14±2.29	73.92±1.93	140.04±3.79	4.47±0.12	57.09±9.76	17.10±0.54

Acknowledgments

References

[1].   Allotey, J. (1991). *Environmental income*. New York Action Plan, Environmental Protection Council (EPC), Ghana. pp. 36-55, 94-95.

[2].   Boateng, T.K., Opoku, F., Osafo Acquaah, S. and Osei Akoto (2015). Pollution evaluation, sources and risk assessment of heavy metals in hand‑dug wells from Ejisu‑Juaben Municipality, Ghana. Boateng *et al. Environmental Systems and Research*, 4:18. https://dx.doi.org/10.1186/s40068-015-0045-y.

[3].   Owusu, P.A., Asumadu-Sarkodie, S. and Ameyo, P. (2016). A review of Ghana's water resource management and the future prospect. *Cogent Engineering*, 3 (1164275): 1-14. https://dx.doi.org/10.1080/23311916.2016.1164275

[4].   BC Wild/EMC of BC (1998). *Acid mining drainage: Mining and water pollution issues in BC*, Environmental Mining Council (EMC) of British Columbia (BC) Victoria, BC, Canada. hpp://www.protectfishlake.ca/media/amd.pdf

[5].   Devi, N.L. Chandra, Y.I., and Shihua, Q.I. (2009). Recent status of arsenic contamination in groundwater of northeastern India: A review. *Report and Opinion*, 1(3): 22-32. http://www.sciencepub.net.

[6].   IPCS (2001). *Environmental health criteria for arsenic and arsenic compounds (EHC 224). International Programme on Chemical Safety (IPCS)*, World Health Organization (WHO), Geneva. https://www.inchem.org/documents/ehc/ehc/ehc224.htm

[7].   Steiner-Aseidu, M., Anderson, A.K., Vuvor, F. and Aseidu, D.K. (2010). Exposure to arsenic in drinking water-Public health debates and concerns. *Research Journal Environmental Earth Sciences*. 2(1):1-5.

[8].   NRC (2001). *Arsenic in drinking water*, National Research Council (NRC), Washington, DC: National Academy Press.

[9].   WHO (2003). *Arsenic in drinking-water*. Background document for preparation of WHO Guidelines for drinking-water quality. Geneva, World Health Organization (WHO/SDE/WSH/03.04/75).

[10].   Banerji, T. and Chaudhari, S. (2016). Arsenic removal from drinking water by electrocoagulation using iron electrodes: An understanding of the process parameters, *Journal of Environmental Chemical Engineering*, 4(4): 3990-4000. https://doi.org/10.1016/j.jece.2016.09.007

[11].   Clifford, D.A., G. Ghurye, and A. R. Tripp (2004). Arsenic removal from drinking water using ion-exchange with spent brine recycling, *Journal of American Water Works Association*, 35(6): 119-130.

[12].   IARC (2012). *Arsenic, metals, fibres and dusts*, Volume 100C. International Agency for Research on Cancer (IARC) Monographs on review of human cancinogens, March 17-24, 2009, Lyon, France, World Health Organization (WHO), Geneva.

[13].   Frank, P. and Clifford, D.A. (1986). Arsenic (III) oxidation and removal from drinking water, PB 86-158 607/AS, 80 pp., 1986, NTIS, Springfield, VA.22161, Summary report EPA/600/52-86/021, 8 pp., U.S. EPA, Cincinnati, OH 45268, April, 1986.

[14].   Ghurye, G. and Clifford, D.A. (2001). *Laboratory study on the oxidation of Arsenic III to Arsenic V*, EPA/600/R-01/021, USEPA Office of Research and Development, Washington, DC.

[15].   Ghurye, G. and D. A. Clifford 2004). Arsenic III oxidation using chemical and solid-phase oxidants, *Journal of American Water Works Association*, 96 (1):84-96.

[16].   Jiang, J.Q. (2001). Removing arsenic from groundwater for developing world: A review, *Water Science and Technology*, 44(6): 89–98.

[17].   Rodríguez , E., Onstad, G.D., Kull, T.P.J., Metcalf, J.S., Juan L., Acero, J.L. & Gunten, U. (2007). Oxidative elimination of cyanotoxins: Comparison of ozone, chlorine, chlorine dioxide and permanganate, *Water Research*, 41(15): 3381-3391.

[18]. MWRWH (2007). *National Water Policy*, Ministry of Water Resources, Works and Housing (MWRWH), Accra, Ghana.

[19]. TNMA MTDP 2014-2017 (2015). *Tarkwa Nsuaem Municipal Assembly (TNMA) Medium Term Development Plan (MTDP) 2014-2017*; Ghana Shared Growth and Development Agenda II, September, 2015, Tarkwa, Ghana.

[20]. Asamoah, D.N. Amorin, R. (2011). Assessment of the Quality of Bottled/Sachet Water in the Tarkwa-Nsuaem Municipality (TM) of Ghana, *Research Journal of Applied Sciences, Engineering and Technology* 3(5): 377-385.

[21]. GSS (2014). *2010 population and housing census: District analytical report of Tarkwa Nsuaem Municipality, Ghana Statistical Service (GSS)*, Accra. https://www.statsghana.gov.gh

[22]. Walsh, A. (1955). The application of atomic absorption spectra to chemical analysis, *Spectrochimica Acta*, 7: 108–117.

[23]. Koirtyohann, S.R. (1991). A history of atomic absorption spectrometry, *Analytical Chemistry*, 63(21): 1024a-1031a. https://dx.doi.org/10.1021/ac0002a716

[24]. WHO (2004). *Guidelines for drinking–water quality*, 3rd edition: Recommendations, World Health Organization (WHO), Geneva.

[25]. WHO (2009). *Guidelines for drinking–water quality*, World Health Organization (WHO) Press, Geneva.

[26]. WHO (2011). *Manganese in drinking-water*. Background document for development of WHO guidelines for drinking-water quality (GDWQ), 4th edition: World Health Organization (WHO), Switzerland, Geneva.

[27]. Järup, L (2003). Hazards of heavy metal contamination, *British Medical Bulletin*, 68 (68): 167–182. https://dx.doi.org/10.1093/bmb/ldg032

[28]. Kumar, M., Subhash, S.C. and Kumar Jha, M. (2016). Heavy metals concentration Assessment in ground water and general public health aspects around Granite mining sites of Laxman pura, U.P., Jhansi. *International Research Journal of Environment Sciences*, 5(1): 1-6.

[29]. Kondakis, X.G, Makris, N, Leotsinidis, M, Prinou, M and Papapetropoulos, T. (1989). Possible health effects of high manganese concentration in drinking water. *Archives of Environmental Health*, 44 (3):175–178. https://dx.doi.org/10.1080/00039896.1989.9935883.

[30]. Armfield, J.M. (2005). Public water fluoridation and dental health in New South Wales. *Australia/New Zealand Journal of Public Health*, 29(5): 477-483.

[31]. Armfield, J.M. (2008). The benefits of water fluoridation across areas of differing socioeconomic status. *Australian Dental Journal*, 53(2):180-183, https://dx.doi.org/10.1111/j.1834-7819.2008.00030.x.

[32]. Bassin E.B., Wypij, D., Davis, R.B. and Mittleman, M.A. (2006). Age-specific fluoride exposure in drinking water and osteosarcoma (United States). *Cancer Causes and Control*, 17(4): 421-428.

[33]. Blakey, K., Feltbower, R.G., Parslow, R.C., et al. (2014). Is fluoride a risk factor for bone cancer? Small area analysis of osteosarcoma and Ewing sarcoma diagnosed among 0–49-year-olds in Great Britain, 1980–2005. *International Journal of Epidemiology*, 43(1), https://dx.doi.org/10.1093/ije/dyt259.

[34]. Stoddard, J.L; Larsen, D.P, Hawkins, C.P, Johnson, R.K. and Norris, R.H. (2006). Setting expectations for the ecological condition of streams: The concept of reference condition, *Ecological Applications*, 16(4): 1267–1276.

[35]. L'hirondel, J. and L'hirondel, J.L. (2002). *Nitrate and man*: *Toxic, harmless, or beneficial?* CABI Publishing, Wallingford, Oxfordshire, UK.

[36]. Powlson, D.S., Addiscott, T.M., Benjamin, N., Cassman, K.G., de Kok, T.M., van Grinsven, H., L'hirondel, J.-L., Avery, A.A. and van Kessel, C. (2008). When does nitrate become a risk for humans? *Journal of Environmental Quality*, 37:291-295. https://dx.doi.org/10.2134/jeq2007.0177.

[37]. Ward, M.H., de Kok, T.M., Levallois, P., Brender, J. Gulis, G. Nolan, B.T. and VanDerslice, J. (2005). Workgroup report: Drinking water nitrate and health: Recent findings and research needs. *Environmental Health Perspectives*, 113:1607–1614.

[38]. Ward, M.H., de Kok, T.M., Levallois, P., Brender, J. Gulis, G. Nolan, B.T. and Van Derslice, J. (2006). Respond to dietary nitrate: Where is the risk? *Environmental Health Perspectives* 114:A459–A460.