academicJournals

Vol. 10(17), pp. 584-590, 7 May, 2016
DOI: 10.5897/AJMR2016.7925
Article Number: 14DC5CC58264
ISSN 1996-0808

http://www.academicjournals.org/AJMR

African Journal of Microbiology Research

Full Length Research Paper

Bacteriological quality and metal levels of boreholes and hand-dug well within the Golden Star Wassa mining areas in Ghana

Addo M. G.*, Oti-Boateng W. and Obiri-Danso K.

Department of Theoretical and Applied Biology, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Received 15 January, 2016; Accepted 25 February, 2016

This study seeks to assess the bacteriological, physicochemical and some trace metals levels in water samples from seven boreholes and a hand-dug well within communities of Golden Star Wassa Mine Limited in Ghana. Five of the sampling sites were slightly acidic and were below the lower limit of the acceptable World Health Organization (WHO) and Ghana Standard Authority (GSA) permissible guidelines for pH. However, sampling from Kubekro well BH04, Akyempim BH07 and at New Akosombo BH06 reported pH mean of 6.9±0.352, 6.7±0.696 and 6.6±0.283, respectively. Well BH02 and that of BH06, respectively reported True Colour mean values of 36.5±6.097 and 17.4±1.930 true colour units (TCU) which were above the WHO/GSA permissible value of 15 TCU. Electrical conductivity, total dissolved solids (TDS), alkalinity, and total hardness were below their respective WHO/GSA permissible limits in the sampling sites with 100% compliance. Pb, Zn, As, Hg, Cu, and Fe recorded a marginal degree of non-compliance with their respective WHO/GSA guideline values of 0.01 mg/L for Pb, 3.0 mg/L for Zn, 0.01 mg/L for As, 0.006 mg/L for Hg and 0.3 mg/L for Fe in all the sampling sites except Cu. All the boreholes indicated a non-detectable microbial load (total coliforms and *Escherichia coli*) except the hand-dug well at Kubekro Well (BH02) which showed some amount of total coliform bacteria load of 6±6.594 coliforms forming unit (CFU). The mechanised borehole groundwater sources within the study area, except the well at BH02 is good for drinking, and hence have not been adversely impacted by mining operations baring the continuous impoundment of the gold processing tails or slurry.

Key words: Groundwater, physicochemical, microbial and trace metal parameters, sampling sites.

INTRODUCTION

Potable and adequate water supply services are a prerequisite for public health and water-quality index is also one of the most effective tools used in passing information on the quality of water to the concerned citizens and policy makers (Atulegwu and Njoku, 2004). Potability is therefore an important parameter for the

*Corresponding author. E-mail: maddosci@yahoo.co.uk.

assessment and management of water (Fagbote et al., 2014). Many mining companies recognize this as a critical commodity, but water use, which ultimately depends on the needs, the area, quantity and availability, has immense implication for the community. Groundwater quality evaluations in different parts of the world have been studied by various researchers in the last two decades (Gallardo and Tase, 2007; Partey et al., 2010). Shah et al. (2008) have compared groundwater quality in Gandhinagar Taluka in India with standard values given by World Health Organization (WHO, 2011) and have come up with a water-quality index for that area. Good quality of water resources depends on a large number of physico-chemical parameters and biological characteristics (Medudhula, 2012).

Many water resources in developing countries are unhealthy, because they contain harmful physical, chemical, and biological agents as a result of geological formation which may impact negatively on the water quality and thus affect human health (Aghazadeh and Mogaddam, 2010). In fact, heavy metal contamination of ground, stream and river water ecosystem is a worldwide environmental problem (Sekabira et al., 2010). Anthropogenic activities tend to impact negatively on aquatic ecosystems through alterations in hydrology, introduction of toxic chemicals and changes to other physicochemical and microbiological traits of water (Paul and Meyer, 2001; Asonye et al., 2007).

Water can be a risk issue for mine sites and its reliability in terms of scientific evaluation may be questioned (Brown, 2010).

Most mining communities in Ghana, depend mostly on well and boreholes as their main source of water. Generally, mining in Ghana is faced with a lot of environmental challenges such as water pollution arising from poor handling of ore processing tailings facilities and waste dump sites, land degradation through loss of vegetation cover and soil erosion (Smedley et al., 1996). As a result, there is growing awareness of mining activities that have been undertaken but with little concern for the environment. Groundwater quality may also be compromised as a result of anthropogenic activities close to boreholes and shallow hand dug wells. Poor sanitation, improper waste disposal, seepage of agrochemicals and mining have been observed to affect the quality of groundwater (Fianko et al., 2010; Jain et al., 2009). To date, no studies have specifically addressed these threats in relation to pit latrines spatial differences and groundwater quality. In view of this, there is still the need to qualitatively ascertain whether the ground water around the catchment communities of Golden Star Wassa Limited (GSWL) mine site is potable for drinking and useful for other domestic purposes.

The area under this study (Golden Star Wassa Limited Catchment Areas) has not been scientifically studied even though the communities around the catchment area largely depend on borehole water installed by the company for drinking and other domestic activities. The importance of the groundwater resources in the area should not be underestimated, because they are the only water resource for drinking. Despite the importance of boreholes and hand dug wells in the Golden Star Wassa Limited Mining Catchment Areas, little is known about the natural phenomena that govern the hydrochemical and bacteriological composition of the groundwater. Thus, there is the need to continuously assess the water quality of boreholes and hand dug wells in these catchment areas. The study focuses on groundwater quality provided by the GSWL to the communities in the catchment areas in order to address its suitability as drinking water with the standards provided by the WHO and that of the Ghana Standard Authority (GSA).

Table 1. Sample sites at Golden Star Wassa Limited (GSWL) used for water sampling.

Site code	Name of sampling location
BH02	Kubekro well
BH03	New Borehole at Kubekro
BH04	New Borehole at Togbekrom
BH05	Akyempim New Borehole
BH06	Borehole at New Akosombo
BH07	Akyempim Borehole near JSS school
BH08	Akyempim Borehole near station

MATERIALS AND METHODS

Golden Star Wassa Mine is located at 62 km north of Daboase, 35 km northeast of Tarkwa and 40 km east of Bogoso, in the Mpohor Wassa East District of the Western Region of Ghana. The project vicinity is predominantly rural and there are no main urban settlements within 50 km. The villages of Akyempim, Kubekro, Togbekrom, and the hamlet of Akosombo lie within the closest vicinity of the mine.

Sample collection

Sampling was conducted during the months of November and December, 2012 through to January, February, March and April 2013 from eight different sampling locations around the Golden Star Wassa (Akyempim) Limited (GSWL) listed in Table 1.

All the chemicals and reagents used were of analytical grade, BDH chemicals Limited, United Kingdom. Samples were collected in 500 ml capacity polythene bottle having doubly stopper. Prior to the collection, the well cleaned sample bottles were rinsed thoroughly with the sample water to be collected. Each sample bottle was clearly labeled and relevant details recorded. Water samples collected for metal analysis were preserved with 50% HNO_3 to attain a pH of 2 in order to keep the metal ions in the dissolved state and also to prevent microbial influence (APHA, 2005). At each sampling site, two samples were collected into 500 ml sterilized bottles. These samples were stored in an ice chest containing ice cubes and transported to the Ghana Water laboratory, Takoradi for analysis within 24 h.

Table 2. Physicochemical properties of water samples from seven boreholes and a hand-dug well in the Golden Star Wassa (Akyempim) mine catchment area.

Parameter		BH01	BH02	BH03	BH04	BH05	BH06	BH07	BH08	GSA/WHO Guidelines
pH	Mean	6.300	5.700	6.000	6.900	5.900	6.600	6.700	6.000	6.5-8.5
	SD	±0.434	±0.469	±0.322	±0.352	±0.494	±0.283	±0.696	±0.746	
EC (µS/cm)	Mean	298.300	309.700	208.300	207.000	330.600	207.000	146.100	245.000	1500
	SD	±93.698	±163.318	±52.355	±36.858	±150.421	±36.858	±38.391	±109.625	
TDS (mg/L)	Mean	346.800	105.100	172.800	194.000	168.900	454.000	73.600	135.700	1000
	SD	±99.438	±17.245	±38.627	±61.671	±58.826	±77.876	±29.366	±82.172	
TH (mg/L)	Mean	88.000	50.000	31.000	56.000	73.800	14.300	10.600	28.000	150
	SD	±13.251	±9.066	±4.136	±12.285	±11.414	±2.577	±1.524	±14.531	
Alkalinity (mg/L)	Mean	64.000	44.000	23.600	42.000	18.90	19.000	14.000	14.000	500
	SD	±12.163	±14.230	±2.925	±3.155	±3.637	±1.556	±3.042	±5.355	
True Colour (TCU)	Mean	8.400	36.500	11.800	9.700	14.300	17.400	4.500	12.000	15
	SD	±3.407	±6.097	±0.934	±0.607	±4.360	±1.930	±0.941	±6.758	

SD: Standard deviation.

Water analysis

All the samples were analyzed in the laboratory employing standard methods for physicochemical parameters (pH, electrical conductivity (EC), total dissolved solids (TDS), total alkalinity, total hardness and true colour), microbial properties (Total coliforms and *Escherichia coli*) and some trace metals (Pb, Zn, Hg, Fe, Cu and As). EC, TDS, and pH were measured using potable Orion 5 star sensor multiparameter analyzer from Orion instruments (Model No. Orin 5 Star, S/N: A03158). The physical and chemical analysis of water samples were based on APHA (2005). Heavy metals were analyzed using the Perkin Elmer Optima 5300 DV for Inductively Coupled Plasma-Atomic Emission Spectrometry analysis.

Statistical analysis

Statistical analyses were carried out using AqQA (version 1.1.1) water-quality software and SAS (version 9.2), MINITAB (version 14) and Rockworks (version 15), respectively.

RESULTS AND DISCUSSION

Physicochemical analysis

The physicochemical analysis of the groundwater samples of the eight sampling sites of Golden Star Wassa mine catchment communities was carried out and their mean variation concentrations are shown in Table 2 and Figures 1 and 2. The results showed that TDS mean value ranged from 73.6±29.366 mg/L at BH07 to 454.0±77.876 mg/L at BH06. Even though a health-based value has not been proposed by the WHO, however, a TDS above 1000 mg/L may be objectionable to consumers (Amoako et al., 2011). The EC showed a maximum EC of 330.6±150.421 µS/cm at the BH05 site with a minimum of 146.1±38.391 at BHO7. The low conductivity level is an indication of low levels of dissolved ions in the ground water within the project vicinity. Mean values reported for EC and TDS, respectively are much below the WHO (2011) and GSA (2009) compliance limit of 1500 µS/cm and 1000 mg/L, respectively (Table 2), giving a compliance percentage of 100% for both parameters. The large variation in TDS values may be attributed to the variation in geological formations, hydrological processes, and the prevailing mining conditions in the region (Liu et al., 2012).

The mean total hardness ranges from 10.6±1.524 mg/L at BH07 to 88.0±13.251 mg/L at site BH01. Singh et al. (2012) have stated that hardness of water mainly depends upon the amount of calcium or magnesium salt or both. It is also an important criterion for determining the usability of water for domestic, drinking and many industrial supplies (Mitharwal et al., 2009). The relative lower values recorded in this study for the hardness of water may be due to the presence of lower concentrations of dissolved calcium and magnesium in these water sources.

Ayers and Westcot (1985) reported that the pH of the water is always an I ndicator of its quality and normally

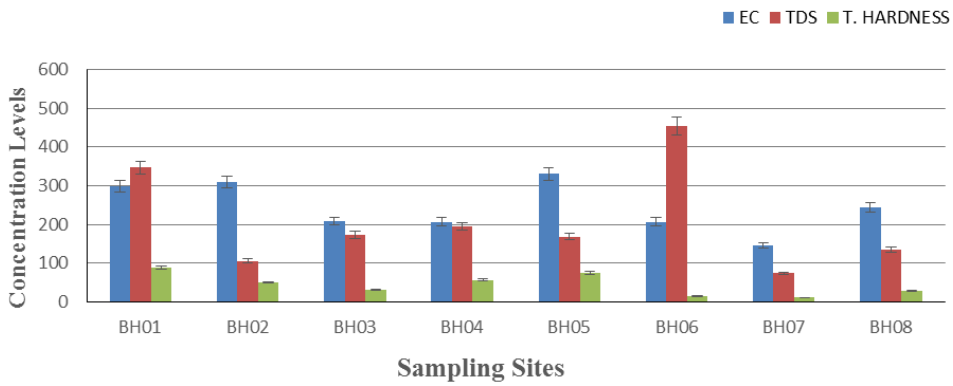

Figure 1. Variation of mean Electrical Conductivity, Total Dissolve Solids and Total Hardness concentration in boreholes and hand dug well.

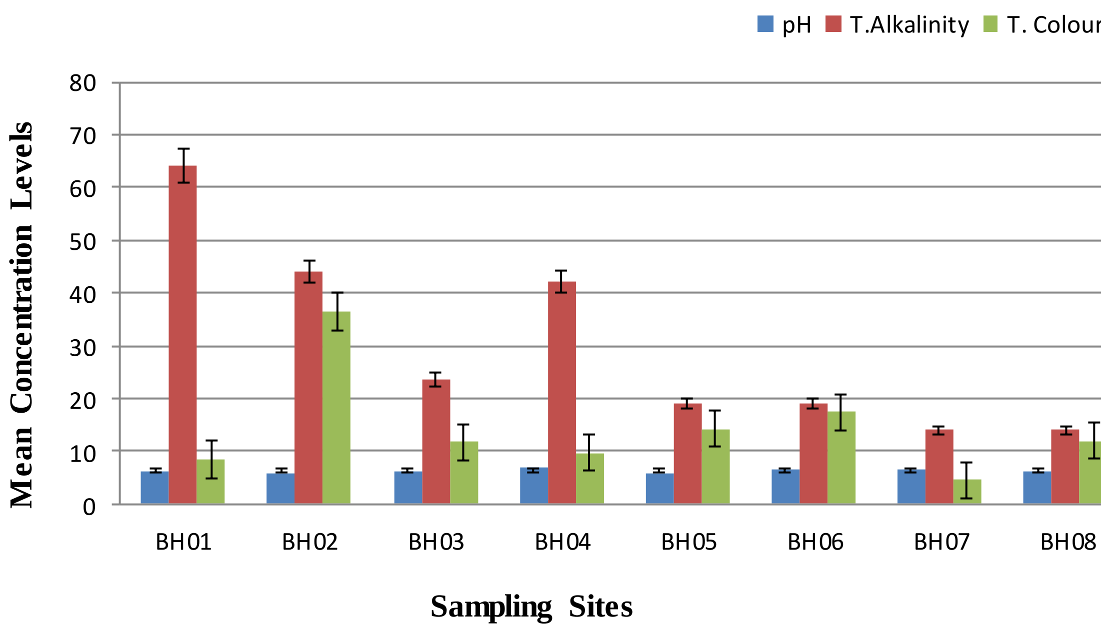

Figure 2. Variation of mean pH, True colour and Total Alkalinity in boreholes and hand dug well.

ranges from 6.5 to 8.4. The study showed that pH varied between 5.7±0.469 at BH02 and 6.9±0.283 at BH04 (Table 2 and Figure 2). Five of the eight sampling sites were slightly acidic and were below the lower limits of WHO (2011) and that of GSA (2009). This could largely be attributed to the geology of the area since the baseline assessment confirms acidic nature of the area, hence, a non-compliance regime of 62.5%. Mitharwal et al. (2009) also reported that the pH of water is a very important indicator of its quality and provides information in many types of geochemical equilibrium.

Results from the analysis of the true colour indicated that two out of the eight sampling sites showed a mean concentration values of 36.5±6.097 TCU at BH02 and 17.4±1.9930 TCU at BH06 (Table 2 and Figure 2). The maximum permissible concentration of true colour for drinking water is 15TCU, based on taste considerations (WHO, 2011). Alkalinity ($CaCO_3$) is the capacity of a solution to neutralise acids. The present study revealed that the mean values for total alkalinity ($CaCO_3$) measured ranges from 14.0±3.042 and 14.0±5.355 mg/L, respectively at BH07 and BH08 to 64.0±12.163 mg/L at BH01. Generally, all the sampling sites analyzed achieved 100% compliance with the WHO (2000) and GSA (2009). This is expected since pH is positively correlated with conductivity and total alkalinity (Figures 1 and 2). Specifically, the results from the environmental baseline assessment of the Wassa mine suggest that the

Table 3. Trace metal levels in water samples from seven boreholes and a hand-dug well in the Golden Star Wassa (Akyempim) mine catchment area.

Parameter		BH01	BH02	BH03	BH04	BH05	BH06	BH07	BH08	GSA/WHO Guidelines
Pb	Mean	0.001	0.001	0.001	0.020	0.040	0.001	0.002	0.004	0.01
	SD	±0.000	±0.001	±0.000	±0.000	±0.011	±0.000	±0.000	±0.000	
Zn	Mean	1.540	3.760	2.340	4.670	0.200	1.890	0.140	0.042	3.0
	SD	±0.363	±1.630	±0.932	±1.780	±0.115	±0.157	±0.103	±0.029	
Hg	Mean	0.010	0.001	0.010	0.020	0.001	0.001	0.001	0.001	0.006
	SD	±0.000	±0.000	±0.000	±0.000	±0.000	±0.000	±0.000	±0.000	
Fe	Mean	0.010	3.800	0.001	0.250	0.025	0.020	7.480	0.010	0.3
	SD	±0.000	±1.686	±0.000	±0.215	±0.014	±0.011	±2.977	±0.000	
Cu	Mean	1.800	1.750	1.200	0.120	0.100	0.020	0.340	0.020	2.0
	SD	±0.543	±0.868	±0.497	±0.093	±0.056	±0.000	±0.268	±0.014	
As	Mean	0.020	0.001	0.010	0.010	0.001	0.010	0.001	0.001	0.01
	SD	±0.006	±0.000	±0.000	±0.000	±0.000	±0.000	±0.000	±0.000	

SD: Standard deviation.

soils have been mostly developed on weathered products on lower Birimian rocks (GSWL EMP, 2010). Domenico (1972) reported that hydrochemical properties of groundwater also depend on lithology, regional flow pattern of water, and resident time.

Trace metal analysis

The concentration of trace metals (Pb, Zn, Hg, Fe, Cu and As) was analyzed in the groundwater samples collected from the sampling sites (Table 3). For the protection of human health, guidelines for the presence of heavy metals in drinking water have been set by different International Organizations such as USEPA, WHO, EPA, and the European Union Commission (Min et al., 1996; Anyakora and Momodu, 2010). Heavy metals have maximum acceptable concentration in drinking water as specified by these organizations. In this study, only Cu showed 100% compliance with the GSA (2009) and WHO (2011) permissible guidelines. High levels of copper in drinking water can cause vomiting, abdominal pain, nausea, diarrhea and have been reported that copper leached into drinking water from copper pipes (DTMRP, 2001). On the other hand, Pb, Zn, Hg, Fe and As indicated traces of non-compliance (Table 3).

According to Smedley et al. (2002), under natural conditions, the greatest range and highest concentrations of As are found in groundwater as a result of the favourable conditions for As mobilization and accumulation. In the present investigation, three of the sampling locations analyzed (BH01, BH03 and BH04) reported a non-compliance mean Hg concentration of 37.5% (Table 3). These sites are reportedly associated with the historical gold ore processing with mercury from anti-sanal activities in the study area. Asklund and Eldvall (2005) reported that sorption can considerably lower the metal concentration like Fe in ground water. The high concentration of Fe in the BH02 and BH07 samples is evidence of richness in naturally occurring Fe concentration in those locations (geology) which through dissolution and infiltration gets into underground water. Even though 75% of all the sampled locations reported compliance with the Maximum Compliance Limit (MCL) of WHO (2011) and GSA (2009) of 0.010 mg/L for Pb, there were marginally high levels of Pb recorded in BH04 and BH05. These results raise much concern since lead is known to be a poisonous metal that can damage nervous connections and cause blood and brain disorders (Ehi-Eromosele and Okiei, 2012). Nkansah et al. (2011) report that lead in water resources is mostly attributed to haphazard disposal of waste from lead containing substances. The mean concentration of Zn for six sampled locations showed values of 75% compliance with the WHO (2011) and GSA (2009) maximum permissible limit of 3.0 mg/L for Zn. Recorded exceedance of Zn in boreholes at BH02 and BH04 might be as a result of the mobilization of Zn in seepage from waste dump and surface water sources which are facilitated by high levels of iron presence.

Table 4. Mean concentrations of metals in water sampled from seven boreholes and the hand-dug well.

Parameter (CFU/100 ml)		BH01	BH02	BH03	BH04	BH05	BH06	BH07	BH08
Total coliforms	Mean	ND	6.000	ND	ND	ND	ND	ND	ND
	SD	-	±6.594	-	-	-	-	-	-
E. coli	Mean	ND	ND	ND	ND	ND	ND	ND	ND
	SD	-	-	-	-	-	-	-	-

ND: Not detected.

Bacteriological analysis

The results of the bacteriological analysis revealed that no coliform was detected in the seven sampled boreholes (Table 4). However, the hand-dug well at BH02 recorded a mean total coliform value of 6±6.594 CFU/100 ml, indicating non-conformity with the WHO (2011) and GSA (2009) guidelines of 0 CFU/100 ml. This might be due to septic pits and latrines in the vicinity that had extended their influence on water qualities. Cairncross and Cliff (1987) have shown that soakage pits and pit latrines can extend their influence on ground-water quality up to 10 m or more as groundwater flow is either lateral or vertical. This is of concern since water from the hand-dug well may contain a microbiological agent that may pose a health problem and that some action is needed (Brian, 2012). It is however, important to note that coliform bacteria are widely found in nature and do not necessarily indicate faecal pollution (Binnie et al., 2002; Griffith et al., 2003). Water from deep boreholes is normally free of pathogenic microbial contaminants due to the relatively slow subsurface movement of water compared to water sources like deep wells which are open and heavily polluted (Zvidzai et al., 2007).

Conclusion

The results showed that only Cu showed 100% compliance with the WHO (2011) and GSA (2009) permissible guidelines while Pb, Zn, Hg, Fe and As indicated traces of non-compliance as follows, respectively; 25% for Pb, Zn and Fe, respectively, 37.5% for Hg and 12.5% for As. It was also observed that the mechanised borehole groundwater sources within the study area is good for drinking in its bacteriological, chemical and metal content and hence have not been adversely impacted on by the mining operations baring the continuous impoundment of the gold processing tails or slurry. In spite of this, the hand dug well at BH02 should be monitored regularly in terms of spatial difference between the refuse dump and the proximity of the closest household latrine near the well site to ensure compliance with the WHO/GSA guideline for quality and potable water.

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES

Aghazadeh N, Mogaddam AA (2010). Assessment of groundwater quality and its suitability for drinking and agricultural uses in the Oshnavieh Area, Northwest of Iran. J. Environ. Prot. 1:30-40.

Amoako J, Karikari AY, Ansa-Asare OD (2011). Physico-chemical quality of boreholes in Densu Basin of Ghana. Appl. Water Sci. 1:41-48.

Anyakora CA, Momodu MA (2010). Heavy metal contamination of ground water: The Surulere case study. Res. J. Environ. Earth Sci. 2(1):39-43.

APHA (American Public Health Association) (2005). American Water Works Association & Water Environment Federation. Standard methods for the examination of water and wastewater (21st ed.).Washington, DC: American Public Health Association.

Asklund R, Eldvall B (2005). Contamination of water resources in Tarkwa mining area of Ghana. M.Sc. Thesis, Department of Engineering Geology, Lund University, Lund, Sweden.

Asonye C, Okolie N, Okenwa E, Iwuanyanwu U (2007). Some physico-chemical characteristics and heavy metal profiles of Nigerian rivers, streams and waterways. Afr. J. Biotechnol. 6:617-624.

Atulegwu P, Njoku J (2004). The impact of biocides on the water quality. Int. J. Environ. Sci. Technol. 1:47-52.

Ayers RS, Westcot DW (1985). Water quality for agriculture. FAO, Rome.

Binnie C, Kimber M, Smethurst G (2002). Basic water treatment. Royal Society of Chemistry, Cambridge. UK.

Brian O (2012). Water Quality: your private well: what do the results mean? www.bfenvironmental.com/pdfs/Waterbooklet070610.pdf.

Brown A (2010). Reliable Mine Water Technology. Mine Water Environ. 29:85-91.

Cairncross S, Cliff JL (1987). Water use and health in Mireda, Mozambique. Trans. R. Soc. Trop. Med. Hyg. 81:51-54.

Darthmouth Toxic Metal Research Programme (DTMRP), (2001). A program of Centre for Environmental Health Science at Darthmouth. www.dartmouth.edu › home › toxic-metals › more-metals

Domenico PA (1972). Concepts and models in groundwater hydrology. McGraw-Hill, New York.

Ehi-Eromosele CO, Okiei WO (2012). Heavy Metal Assessment of Ground, Surface and Tap Water Samples in Lagos Metropolis Using Anodic Stripping Voltammetry. Resour. Environ. 2(3):82-86.

Fagbote E, Olanipekun E, Uyi H (2014). Water quality index of the ground water of bitumen deposit impacted farm settlements using entropy weighted method. Int. J. Environ. Sci. Technol. 11:127-138.

Fianko JR, Nartey VK, Donkor A (2010). The Hydrochemistry of groundwater in rural communities within the Tema Disrict, Ghana. Envion. Monit. Assess. 168:441-449.

Gallardo AH, Tase N (2007). Hydrogeology and geochemical characterization of groundwater in a typical small-scale agricultural area of Japan. J. Asian Earth Sci. 29:18-28.

GSA-Ghana Standards Authority (2009). Limits for Drinking water (GS 175-1:2009/3rd Edition)

Griffith JF, Weisberg BS, McGee DC (2003). Evaluation of microbial source tracking methods using mixed faecal sources in aqueous test samples. J. Water Health 1:141-151.

GSWL EMP. (2010). Environmental Management Plan for Wassa Mine. (Unpublished)

Jain CK, Bandyopadhyay A, Bhadra A (2009). Assessment of groundwater quality for drinking purpose, District Nainital, Uttarakhand, India. Environ. Monit. Assess. 166(1-4):663-676.

Liu MX, Yang JS, Li XM, Mei Yu, Wang J (2012). Effects of irrigation water quality and drip tape arrangement on soil salinity, soil moisture distribution, and cotton yield (*Gossypium hirsutum* L.) under mulched drip irrigation in Xinjiang, China. J. Integr. Agric. 11(3):502-511.

Medudhula TS (2012). Analysis of water quality using physico-chemical parameters in lower Manair Reservoir of Karimnagar District,Andhra Pradesh. Int. J. Environ. Sci. *3*(1):172-180.

Min KS, Onosaka S, Tanaka K (1996). Renal accumulation of cadmium and nephropathy following long-term administration of cadmium-metallothionein. Toxicol. Appl. Pharmacol. 141(1):102-109.

Mitharwal S, Yadav RD, Angasaria RC (2009). Water Quality analysis in Pilani of Jhunjhunu District (Rajasthan) - The place of Birla's Origin. Rasayan J. Chem. 2(4):920-923.

Nkansah MA, Ofosuah J, Boakye S (2011). Quality of Groundwater in the Kwahu West District of Ghana. Environ. Res. J. 5(2):31-37.

Partey FK, Land LA, Frey B (2010). Final report of the geochemistry of bitter lakes national wildlife refuge. New Mexico Bureau of Geology and Mineral Resources, Roswell, 19.

Paul MJ, Meyer JL (2001). Streams in the urban landscape. Annu. Rev. Ecol. Syst. 32:333-365.

Sekabira K, Origa HO, Basamba TA, Mutumba G, Kakudidi E (2010). Heavy metal assessment and water quality values in urban stream and rain water. Int. J. Environ. Sci. Technol. 7(4):759-70.

Shah MC, Shilpkar PG, Acharya PB (2008). Ground water quality of Gandhinagar Taluka, Gujarat, India. J. Chem. 5:435-446.

Singh MK, Jha D, Jadoun J (2012). Assessment of Physico-chemical status of Groundwater Samples of Dholpur District, Rajasthan, India. Int. J. Chem. 4(4):96-104.

Smedley PL, Edmunds WM, Pelig-Ba KB (1996). Mobility of arsenic in groundwater in the Obuasi gold-mining area of Ghana: Some implications for human health. Environ. Geochem. Health 113:163-181.

Smedley PL, Nicolli HB, Macdonald DMJ, Barros AJ, Tullio JO (2002). Hydrogeochemistry of arsenic and other inorganic constituents in groundwaters from La Pampa, Argentina. Appl. Geochem. 17:259-284.

WHO (World Health Organization) (2011). Water and sanitation. Guidelines for drinking-water quality. www.who.int/water_sanitation_health/dwq/chemicals/copper.pdf.

Zvidzai C, Mukutirwa T, Mundembe R, Sithole-Niang I (2007). Microbial community analysis of drinking water sources from rural areas of Zimbabwe. Afr. J. Microbiol. Res. 1(6):100-103.