



Evaluation of heavy metal pollution index of groundwater in the Tarkwa mining area, Ghana

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ABSTRACT

Concentrations of eight heavy metals: Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn were determined and used to evaluate the heavy metal pollution index (HPI) adopting two different approaches. In the first instant heavy metals that were not detected by the instrument is assigned zero concentration. In the second instance, these heavy metals were assigned the limit of detection of the instrument as if they were present to that extent. The two approaches used in the computation of HPI for the groundwater based on the mean concentrations of the selected heavy metals and the limit of detection of the instrument gave similar results. The HPI of the groundwater was generally below the critical value of 100 with the exception of one point which has an overcritical HPI value of 102.97.

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Introduction

The exploitation of groundwater for the water supply needs of many rural communities in Africa has been on the increase in the last decade and, in Ghana, groundwater continues to play an important role in the socioeconomic development of the country. Realizing that most surface water resources are polluted, the government of Ghana has shifted attention from developing surface water resources to groundwater resource development and to supply communities in rural communities because of the anticipated high cost of treating polluted surface water resources (Kortatsi, 2007). From an exploration survey carried out in Ghana by the Water Research Institute (WRI, 1993), about 90% of the rural and 25% of the urban communities depend largely on groundwater for their domestic water needs.

There are about 56,000 abstraction systems Groundwater development in the Wasswa West District, which is home to major mining communities have often been hampered among other problems by contaminants from mining and mining related activities, improper waste disposal, leakage of underground storage tanks, and seepage of agrochemicals from municipal and agricultural fields (Akabza, 2000).

A lot of studies are abound in the literature on heavy metal pollution of water sources. Such works include those of Edet and Ntekim (1996), Yang *et al.* (1996) and Yiping (1996). All these authors concluded thus that there was the need to monitor water quality on a regular basis. This is because the increase in concentration of heavy metals in potable water will increase the threat to man's health and life. In addition, several methods exist in literature on the development and application of pollution index methods for water quality assessment. Some of these include the work of Horton (1965), Tiwary and Mishra (1985) and Prasad and Jaiprakash (1999).

In this present paper, use is made of the weighted arithmetic average of the concentrations of eight heavy metals; cadmium,

chromium, copper, iron, manganese, nickel, lead and zinc, as the basis of a heavy metal pollution index (HPI) adopting two approaches based on the instrument's limit of detection and the generated data.

General Description of Study Area

The study area is located between Latitude 5.00°N and 5.00 40°N and Longitudes 1.0 45° W and 2.0 10°W covers an area of about total land area of 2354 sq. km. Detailed description of the study area is presented by Yankey *et al.* (2011a). In brief the area forms part of the Birimian and Tarkwaian geological formations which are regarded as the most important formations due to its mineral potentials. It accounts for the existence of many gold and the only manganese mining companies in the Ghana (Kesse, G.O. 1985). Annual rainfall data for the area indicates minimum and maximum values of 1449mm and 2608mm respectively with an annual average of about 1874mm (Bogoso Gold Ltd, 2002). The rocks of the study area do not have adequate primary porosity. The Birimian and Tarkwaian rocks that underlie the area are largely crystalline and inherently impermeable, unless fractured or weathered. Groundwater occurrence is therefore associated with the development of secondary porosity and permeability. The zones of secondary permeability are often discrete and irregular and occur as fractures, faults, lithological contacts and zones of deep weathering (Kortatsi, B. K. 2002). Groundwater in the area is acknowledged to occur in two (2) distinct hydraulically connected aquifer system; an upper weathered zone aquifer and a deeper un-weathered aquifer or fractured zones and dyke contacts (Junner, *et al.* 1942). Aquifers are recharged by direct infiltration of precipitation through brecciate zones and through the weathered outcrop (Kortatsi, B. K. 2002).

Indexing Approach

The HPI, represent the total quality of water with respect to heavy metals. The proposed HPI was developed by assigning arating or weightage (Wi) for each selected parameter. The rating system is an arbitrarily value between zero and one, reflecting the relative importance of individual quality considerations, and can be defined as inversely proportional to the recommended standard (Si) for each parameter (Horton 1965; Mohan et al. 1996; Reddy 1995).

The highest tolerant value for drinking water (Si) refers to the maximum allowable concentration in drinking water in absence of any alternate water source. The desirable maximum value (Ii) indicates the standard limits for the same parameters in drinking water.

The HPI model (Mohan et al., 1996) is given by

$$HPI = \frac{\sum_{i=1}^n WiQi}{\sum_{i=1}^n Wi}$$

where Qi is the sub-index of the ith parameter, Wi is the unit weightage of the ith parameter and n is the number of parameters considered. The sub-index (Qi) of the parameter is calculated by

$$Qi = \sum_{i=1}^n \frac{|Mi - Ii|}{Si - Ii} \times 100$$

where Mi is the monitored value of heavy metal of ith parameter, Ii is the ideal value of the ith parameter and Si is the standard value of the ith parameter in ppb. The quantity [Mi – Ii] indicates numerical difference of the two values, ignoring the algebraic sign; that is the absolute value. Generally, the critical pollution index of HPI value for drinking water is 100 (Prasad and Bose (2001). In computing the HPI, Prasad and Bose (2001) considered unit weightage (Wi) as a value inversely proportional to the maximum admissible concentration (MAC) of the corresponding parameter as proposed by Siegel, (2002). This approach is been applied in this current work.

Experimental work

Groundwater samples were collected individually from a combination of domestic and municipal boreholes into acid-cleaned high-density 1-L linear polyethylene sampling bottles with strict adherence to the sampling protocol as described by Gale and Robins (1989) and analyzed independently using the Standard Methods (1998).

The elemental composition was measured by atomic absorption spectrophotometry (VARIAN AA240FS, USA) after a microwave (ETHOS 900 Microwave, Milestone) assisted digestion.

Results and Discussions

The results of the analysis are presented by way of Figures and Tables below. The quality of the results from the instrument as per Quality Control Chart (Figure 1) is found to be good and reproducible with results varying within two standard deviations (i.e. ±2σ) of the mean.

The descriptive summary statistics including maximum admissible concentration (MAC) are given in Table 1. The concentration of Cr, Cu, Cd, Pb and Zn were below the MAC in drinking water. The Mn concentration (56–852 µg/L) and that of Ni (40-152 µg/L) in all the locations are higher than the MAC of 50 µg/l and 20 µg/L respectively while 37% of the locations exhibited Fe concentration in excess of 200 µg/L.

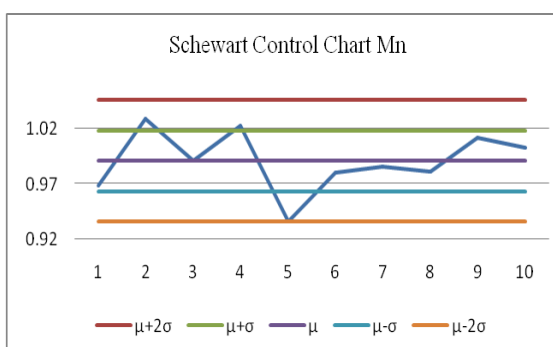
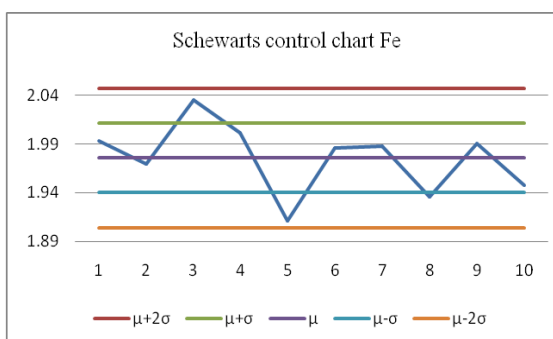
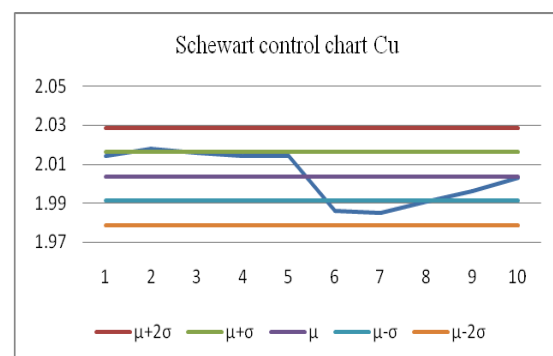
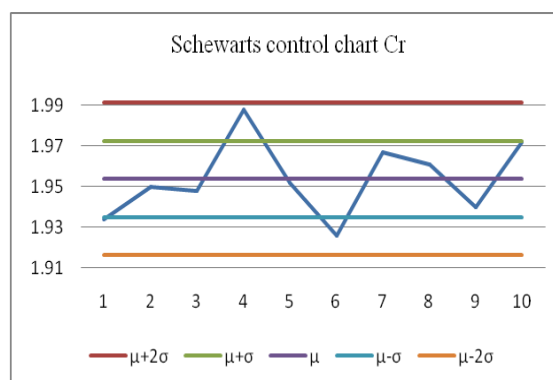
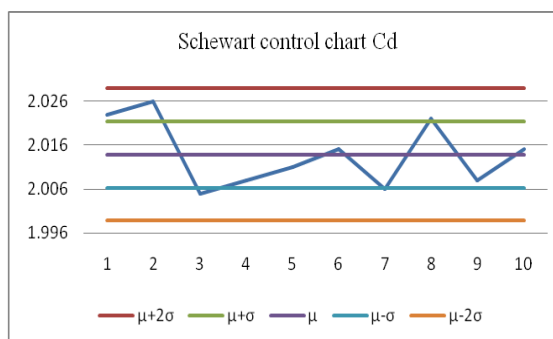


Table 1: Descriptive summary statistics for heavy metals

Parameter	units	min	max	mean	median	stdev	MAC ^a	%>MAC
Temp	°C	25.80	28.30	27.18	27.30	0.64		
pH		4.30	6.70	5.42	5.70	0.66	6.5-8.5 ^b	
E.C	µS/cm	49.00	421.00	205.09	148.10	123.14	1400 ^b	
Cd	µg/L	<2	<2	<2	<2		3	0.00
Cr	µg/L	<1	<1	<1	<1		50	0.00
Cu	µg/L	16.00	92.00	46.25	48.00	21.61	1000	0.00
Fe	µg/L	28.00	8444.00	1476.44	110.00	2543.68	200	37.00
Mn	µg/L	56.00	852.00	337.00	354.00	240.24	50	100.00
Ni	µg/L	40.00	152.00	70.38	57.00	34.33	20	100.00
Pb	µg/L	<10	<10	<10	<10		1.5	0.00
Zn	µg/L	8.00	120.00	27.25	18.00	28.25	5000	0.00

^aMAC Maximum Admissible Concentration (Adapted from Siegel, 2002)^bWHO (2004)**Table 2: Standards used for the index computation**

	W	S	I	MAC	RV
Cd	0.3	5	3	3	0.2
Cr	0.02	50	50	50	1.0
Cu	0.001	1000	2000	1000	3.0
Fe	0.005	300	200	200	50.0
Mn	0.02	100	500	50	5.0
Ni	0.05	20	20	20	0.3
Pb	0.70	100	10	1.5	3.0
Zn	0.0002	5000	3000	5000	5.0

W Weightage (1/MAC)

S Standard permissible in µg/L

I Highest permissible in µg/L

MAC Maximum admissible concentration

RV Reference value in µg/L

Table 3: HPI of groundwater at each sampling point (mean HPI^a=50.08, HPI^b=49.99)

Sampling point	HPI ^a	HPI ^b	mean deviation	% mean deviation	% deviation b/n HPI a & b	HPI Classification
B1	38.63	38.54	-11.95	-23.64	0.23	high
B2	38.73	38.63	-11.84	-23.41	0.26	high
B3	44.20	44.11	-6.37	-12.60	0.20	high
B4	85.54	85.44	34.97	69.15	0.12	high
B5	55.45	55.35	4.88	9.65	0.18	high
B6	38.58	38.48	-11.99	-23.71	0.26	high
B7	40.78	40.68	-9.79	-19.36	0.25	high
B8	70.72	70.62	20.15	39.85	0.14	high
B9	51.57	51.47	1.00	1.98	0.19	high
B10	40.23	40.14	-10.34	-20.45	0.22	high
B11	38.91	38.81	-11.66	-23.06	0.26	high
B12	43.54	43.44	-7.03	-13.90	0.23	high
B13	41.95	41.85	-8.62	-17.05	0.24	high
B14	102.97	102.88	52.40	103.62	0.09	critical
B15	38.70	38.60	-11.87	-23.47	0.26	high
B16	38.85	38.75	-11.72	-23.18	0.26	high

a is based on zero concentration for metals not detected

b is based on instrument's limit of detection

Table 4: Correlation matrix between the parameters

	Temp	HPI ^b	pH	E.C	Cu	Fe	Mn	Ni	Zn	ML	HPI ^a
Temp.	1	-.390	-.017	-.104	-.020	-.402	.034	.132	.101	-.386	-.390
HPI ^b		1	-.339	.300	-.009	.996**	.281	.129	-.030	.999**	1.000**
pH			1	-.407	.162	-.338	-.071	-.279	-.164	-.341	-.339
E.C				1	.118	.280	.332	-.071	-.281	.301	.300
Cu					1	-.006	-.042	.022	-.284	-.005	-.009
Fe						1	.194	.149	.005	.996**	.996**
Mn							1	-.118	-.318	.276	.281
Ni								1	.558*	.154	.129
Zn									1	-.009	-.029
ML										1	.999**
HPI ^a											1

* Correlation is significant at the 0.05 level and **at the 0.01 level ML=metal load

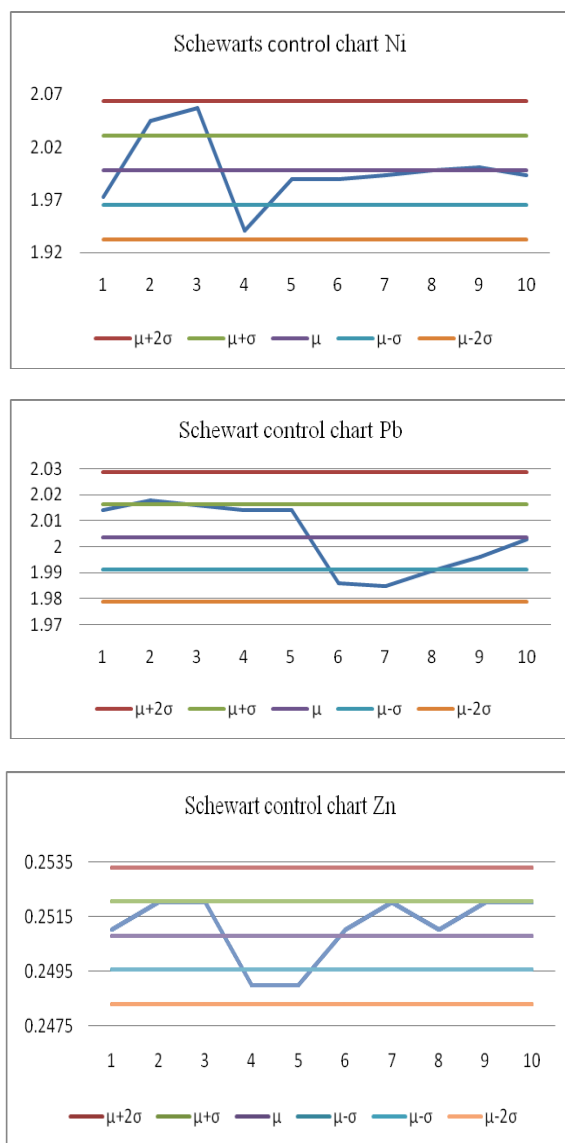


Figure 1: quality control charts for the metals determined by Varian AA240FS

The HPI was calculated by taking the mean concentration value of the selected metals determined using the two equations discussed in the indexing approach. The standards used for the computation of the HPI are given in Table 2 with unit weightage (W_i), standard permissible values (S_i), highest permissible values (I_i) and maximum admissible concentration (MAC) are presented for the groundwater under study.

Two approaches have been used to calculate the HPI values. In the first instance heavy metals that were not detected by the instrument is assigned zero concentration. In the second instance, these heavy metals were assigned the limit of detection of the instrument as if they were present to that extent. The two HPI computations for the groundwater were calculated to be 50.08 and 49.99 respectively. The near sameness of these values indicates that both approaches could be used to calculate the HPI. This assertion is buttressed by the excellent correlation between HPI^a and HPI^b (Table 4). The mean HPI were below the critical value of 100.

The HPI of each sampling point was also calculated separately (Table 3). This enabled comparison of quality of water at each ground water sampling point with respect to the determined heavy metals. For one sampling point, the HPI of the groundwater was below the critical index value of 100, though the HPI values of sampling points B4, B8 and B14 were much

higher than at the other sampling points. In fact all the HPI could be classified as high (i.e. > 30). Sampling point B14 could be described as polluted with an overcritical HPI value of 102.97. This is not surprising as the sampling point had the highest metal load of 9.01 mg/L with iron and manganese contributing a substantial 93%.

Mean deviation and percentage deviation from the mean HPI value was also calculated for each sampling point (Table 3). Eleven sampling points representing 68.75% recorded an index value lower than the mean and the percentage deviation is on the negative side which indicate a better quality of water with respect to the heavy metals.

The correlation analysis of parameters using the Statistical Package for the Social Sciences (SPSS 10.0 package) is presented in Table 4. Correlation at 5% level of significance ($P < 0.05$) demonstrated significant correlation between Nickel and Zinc. The contribution of iron to the metal load and the HPI also manifested in the strong correlation between these three parameters (Table 4). In this area iron in the lithology occurs as hematite (Fe_2O_3), magnetite (Fe_3O_4), pyrite (FeS_2) and arsenopyrite ($FeS_2 \cdot FeAs$) from which the gold is obtained (Kesse, G.O. 1985, Knight and Scott, 2002). This may account for the observed high iron content.

Furthermore, the pH correlated negatively with all metals with the exception of copper. The pH of a solution is dependent on hydrogen ion concentration. Therefore, the positive correlation between pH and Cu in this work is remarkable and consistent with the redox potential of the metal relative to hydrogen.

Conclusions

The two approaches used in the computation of HPI for the groundwater based on the mean concentrations of the selected heavy metals and the limit of detection of the instrument gave identical results. The HPI has also proven to be useful tool in evaluating overall pollution of the groundwater. It indicated that although the HPI of the groundwater at the study area was in general less than critical (< 100), the levels were however high (> 30) and one sampling point could be described as polluted.

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