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Evaluation of Heavy Metal Pollution Index of Groundwater during Dry Season in Winneba-Ghana

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ABSTRACT

Five (5) heavy metals: Cd, Co, Fe, Pb and Zn were monitored in groundwater at three (3) borehole and three (3) hand dug wells and used to evaluate the heavy metal pollution index (HPI) adopting two joined approaches. In the first instance heavy metals that were not detected by the instrument were assigned zero concentration. With the second instance, these heavy metals were assigned the limit of detection of the instrument as if they were present to that extent. These two joined approaches were used in the calculation of HPI for the groundwater based on the mean concentrations of the selected heavy metals and the limit of detection from the instrument. The two (2) approaches gave similar results. The two HPI joined approaches for zero concentration for metals not detected and for the limit of detection of the instrument for metals not detected for the dry season were 0.887 and 0.880 respectively. The near sameness of these values indicates that both approaches could be used to calculate the HPI. There was a significant correlation ($P<0.01$) between the two HPIs. The results indicates that the groundwater monitored is free from the selected heavy metal pollution.

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Introduction

Water quality according to Tiakor, (2015), refers to the chemical, physical, biological and radiological characteristics of water. Third World Academy of Sciences Report (2002) stated that, unsafe water kills more than cancer, accidents or AIDS. It is vital to ensure that the water humans drink become free from pathogens and toxic chemical substances that can threaten public health. This suggests that drinking and using safe water for domestic purposes improves peoples' health and reduces the risk of death caused by unsafe water. The provision of adequate and safe water for drinking and human use is essential for human physiology and existence (Nwosu & Ogueke, 2004). Water resources which contain substances detrimental to health, objectionable taste, colour and odour are unfit for immediate consumption unless subjected to some sort of treatment (Oketola *et al.*, 2006). The level of pollution of raw water can influence the quality of the treated water (Adejuwon & Mbuk, 2011). Water treated for consumption must satisfy one or two standards that conform to WHO drinking water guidelines values. Ensuring that people obtain adequate and quality supply of water for consumption is vital for sustainable development (Khalil & Ouarda, 2009). Heavy metals once released into the environment can remain in waterways for decades or even centuries, in concentrations that are high enough to pose a health risk. Several methods are used to clean up the environment from these kinds of contaminants, but most of them are costly and difficult to get optimum results. Currently, phytoremediation is an effective and affordable technological solution used to extract or remove inactive metals and metal pollutants from contaminated soil and water. This technology is environmentally friendly and potentially cost effective (Tangahu, *et al.*, 2011).

Strong relationship between contaminated drinking water with heavy metals from some of the Great Cairo Cities, Egypt and chronic diseases such as renal failure, liver cirrhosis, hair loss, and chronic anemia was identified in their study. These diseases were apparently related to contaminated drinking water with heavy metals such as Pb, Cd, Cu, Mo, Ni, and Cr. Renal failure was related to contaminated drinking water with lead and cadmium, liver cirrhosis to copper and molybdenum, hair loss to nickel and chromium, and chronic anemia to copper and cadmium. Studies of these diseases suggested that abnormal incidence in specific areas was related to industrial wastes and agriculture activities that have released hazardous and toxic materials into the groundwater and thereby led to the contamination of drinking water in those areas (Bhattacharya, 2020). Cadmium is introduced into the environment through industrial operations including electroplating, reprocessing cadmium scrap and incineration of cadmium containing plastics. Cadmium can also be found in soils because insecticides, fungicides, sludge, and commercial fertilizers are used in agriculture. It may enter drinking water as a result of corrosion of galvanized pipe. Cadmium dispersed in the environment can persist in soils and sediments for decades (Bhattacharya, 2020).

The production and use of iron compounds as catalysts, pigments, drugs, as well as their use in agriculture, nutrition, metallurgy, and leather tanning may result in their release to the environment through various waste streams. The mining and processing of iron ores also may result in the release of iron compounds to the environment. The iron and steel industries are also likely sources of emissions of iron compounds to the environment. Occupational exposure to iron compounds may occur through inhalation and dermal contact with these compounds at workplaces where iron

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compounds are produced or used (Bhattacharya, 2020). Zinc is an essential trace element, necessary for plants, animals, and microorganisms. It is typically the second most abundant transition metal in organisms after iron and it is the only metal which appears in all enzyme classes. Some zinc is released into the environment by natural processes, but most comes from human activities like mining, steel production, coal burning, and burning of waste. Humans are exposed to zinc through drinking contaminated water or a beverage that has been stored in metal containers or flows through pipes that have been coated with zinc to resist rust. Excessive concentrations of zinc taken on a long-term basis can cause anemia and decrease the levels of good cholesterol. Chronic exposure to zinc oxide by skin contact may result in popular-pustular skin eruptions in the axilla, inner thigh, inner arm, scrotum and pubic areas. Excessive absorption of zinc suppresses copper and iron absorption. The U.S. Food and Drug Administration (FDA) has stated that zinc damages nerve receptors in the nose, which can cause anosmia (loss of sense of smell).

Cobalt is found naturally throughout the environment. The general population may be exposed to cobalt in the air, drinking water, and food. Higher-than-normal exposure levels for cobalt can occur in the air and water near industrial areas, particularly near hard metal industrial sites (Bhattacharya, 2020).

Materials/ Methodology

General description of study area

The target areas were some selected communities in Winneba, Effutu municipality. The Effutu Municipality is situated between latitudes 5^{O} 28' and 5^{O} 18' North and longitudes 0^{O} 25' and 0^{O} 40'west on the eastern part of the Central Region of Ghana (Figure 1). It is bordered to the north by the Agona Municipal, on the northeast by the West Akim Municipal, to the south by the Gulf of Guinea, and to the west by the Gomoa District. The Municipality covers an area of about 417.3 km^2. Winneba is the administrative capital of the Effutu Municipal with a population of about 70,592. The Municipality is generally low lying with granite rocks and isolated hills. The two major rivers; Ayensu and Gyahadze drain the Municipality and enter the sea at Worabeba and Opram respectively (GSS, 2014).

The water bodies that drain through the Municipality have the potential to be exploited when dammed for extensive vegetable cultivation during the dry season and for aqua-culture activities. The Municipality lies within the dry-equatorial climatic zone characterized by low rainfall and long dry season of five months. The annual rainfall ranges from 400 to 500 millimeters. Mean temperatures range from 22^0C to 28^0C. The vegetation is that of the coastal savannah grassland which is suitable for vegetable cultivation or dry season irrigation farming. The soils in the Municipality are largely clayey with high salinity hence its suitability for salt production and pottery/roofing tiles production. The famous Aboakyer Festival of the people of the Municipality derived its existence from the annual sacrifices made to the Penkye Otu deity (GSS, 2014). Figure 1 is the map of the study area with the sampling points indicated accordingly

Sampling

Thirty-six (36) samples were collected during the dry season from six (6) sites in six communities in Winneba Municipality which includes: Ansaful, UEW South, Flamengo, Oyibi, Kwendrum, Otuana. These communities were selected based on groundwater availability and usage of groundwater.

Table 1. GPS coordinates of sampling point location

Sampling Sites	Latitude(^{0}N)	Longitude(^{0}E)
BH 1 (UEW south)	760577	595916
BH 2 (Oyibi)	763329	590529
BH 3 (Otuana)	763835	591319
BH 4 (Kwendrum)	763773	591346
BH 5 (Ansaful)	763776	591344
BH 6 (Flamengo)	763658	591713
BH- Borehole		

Water sample collection

Groundwater samples were collected individually with a bucket from a combination of domestic and municipal boreholes into acid cleaned high-density 500mL 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).

Acidification of the water samples was done at the sampling site. 3.0 mL of 30% concentrated HNO_3 was measured and added to 500 mL of the samples, to preserve the water samples and to keep the metal ions in solution. Each sample bottle was visibly labeled and relevant details recorded. All the samples were stored in cold box and transported to the Council for Scientific and Industrial Research, Environmental Chemistry Division. The samples were covered tightly and transported to the laboratory for further treatment.

Digestion of water samples for metal determination

Each sample was thoroughly mixed by shaking and 100 mL of the sample was transferred into a conical flask. About 5.0 mL concentrated HNO_3 and a few boiling chips was added (APHA, 1999). The mixture was then heated until the volume reduced to about 15 mL. Complete digestion was indicated by a light-coloured solution. The content of the conical flask was filtered with Whatman No 42-filter paper. The filtrate was transferred into 100 mL volumetric flask and the volume finally adjusted to 100 mL with distilled water and stored at 4^0C, ready for AAS analysis (APHA, 1999).

Metals determination

(Atomic Absorption Spectrometry – Direct Aspiration)

Heavy metals were determined with the aid of Flame Atomic Absorption Spectrophotometer using an air-acetylene oxidizing flame. Each heavy metal was determined three (3) times to ensure accuracy of the results obtained. For the determination of Lead (Pb), the instrument was calibrated with standard solutions of 0.25ppm, 1.00ppm and 2.00ppm and a lamp with a wavelength of 217.0nm. Instrument detection limit for Lead was 0.005mg/l. For the determination of Iron (Fe), the instrument was calibrated with standard solutions of 0.50ppm, 1.00ppm and 2.00ppm and a lamp with a wavelength of 248.3nm. Instrument detection limit for Iron was 0.010mg/l. For the determination of Cadmium (Cd), the instrument was calibrated with standard solutions of 0.50ppm, 1.00ppm and 5.00ppm and a lamp with a wavelength of 248.3nm. Instrument detection limit for Cadmium was 0.002 mg/l. For the determination of Zinc (Zn), the instrument was calibrated with standard solutions of 1.00ppm, 2.00ppm and 5.00ppm and a lamp with a wavelength of 248.3nm. Instrument detection limit for Zinc was 0.005mg/l. For the determination of Cobalt (Co), the instrument was calibrated with standard solutions of 0.25ppm, 1.00ppm and 2.00ppm and a lamp with a wavelength of 240.7 nm. Instrument detection limit for Cobalt was 0.010 mg/l.

Indexing approach

The HPI, represent the total quality of water with respect to heavy metals. The proposed HPI was developed by

assigning a rating or weightage (Wi) for each selected parameter. The rating system is an arbitrary 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 (Mohan et al. 1996). 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;

$$HPI = \frac{\sum_{i=1}^{n} w_i Q_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

Where Qi is the sub-index of the i^{th} parameter, Wi is the unit weightage of the i^{th} parameter and n is the number of parameters considered.

The unit weight, Wi, is calculated by;

$$W_i = \frac{K}{S_i} \quad (2)$$

The proportionality constant, K is calculated by,

$$K = \frac{1}{\sum_{i=1}^{n} \frac{1}{S_i}} \quad (3)$$

Where,

$$\sum_{i=1}^{n} \frac{1}{S_i} = \frac{1}{s_1} + \frac{1}{s_2} + \frac{1}{s_3} \ldots + \frac{1}{s_i} \quad (4)$$

Where S_1, S_2, S_3, etc. represent standards for different heavy metals in water such as lead, cobalt, cadmium, zinc, iron.

The sub-index (Qi) of the parameter is calculated by;

$$Q_i = \sum_{i=1}^{n} \frac{|M_i - I_i|}{S_i - I_i} \times 100 \quad (5)$$

Where Mi is the monitored value of heavy metal of i^{th} parameter, Ii is the ideal value of the i^{th} parameter and Si is the standard value of the i^{th} 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 & 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 has been applied and adopted by this study.

Results and discussion

The results of the analysis are presented by way of Figures and Tables. The descriptive summary statistics including maximum admissible concentration (MAC) and the concentrations of Cd, Co, Fe, Pb and Zn in drinking water is presented in Table 2.

Table 2. Standards used for the HPI computation

	W	S	I	MAC
Pb	*0.7	10	10	1.5
Fe	*0.005	300	200	200
Cd	*0.3	3	3	3
Zn	*0.0002	2000	3000	5000
Co	*0.001	10	10	1000

Maximum Admissible Concentration (MAC) adapted from Siegel (2002) and WHO (2002)

W-Weightage (1/MAC)

S-Standard permissible in µg/L

I-Highest permissible in µg/L

MAC-Maximum admissible concentration in µg/L

The Descriptive summary statistics table for heavy metals during the dry season is presented in Table 3.

The correlation matrix table between the parameters during the dry season is presented in Table 4.

The HPI of groundwater at each sampling point during the dry season is presented in Table 5.

Table 5. HPI of groundwater at each sampling point during the dry season (mean HPI_A = 0.887 and HPI_B = 0.880)

SAMPLING POINT	HPI_A	HPI_B	HPI Classification
1	0.730	0.730	LOW
2	0.929	0.929	LOW
3	0.999	0.999	LOW
4	0.984	0.984	LOW
5	0.663	0.663	LOW
6	1.019	0.979	LOW

Source: Laboratory data, 2021

The HPI classification table is presented in Table 6

Table 6. HPI Classification Table by Majhi & Biswal, 2016

HPI	Quality of Water
0-25	Very good
26-50	Good
51-75	Poor
Above 75	Very poor (unsuitable for drinking)

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 as given in Table 2 with unit weightage (Wi), standard permissible values (Si), highest permissible values (Ii) 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 zero concentration for metals not detected and for the limit of detection of the instrument for metals not detected for the groundwater were calculated to be 0.887 and 0.880 respectively. The near sameness of these values indicates that both approaches could be used to calculate the HPI. This assertion is buttressed by strong positive significant correlation ($P<0.01$) between the two HPI approaches. The mean HPI were below the critical value of 100. The HPI of each sampling point was also calculated separately (Table 5). This enabled comparison of quality of water at each ground water sampling point with respect to the determined heavy metals. The HPI of the groundwater was below the critical index value of 100. In fact, all the HPI could be classified as low because it is lower than 30.

The correlation analysis of parameters using the Statistical Package for the Social Sciences (SPSS 16.0 package) is presented in Table 4. Correlation at 99% level of confidence ($P<0.01$) demonstrated significant correlation between Zn and E.C. Which corresponds to the increase in the concentration of Zn as E.C increases.

Furthermore, there was a strong positive significant correlation between pH and HPI. The pH also correlated negatively with all the metals. The pH of a solution is dependent on hydrogen ion concentration. Therefore, the negative correlation between pH and all the metals analysed in this work is remarkable and consistent with the redox potential of the metals relative to hydrogen.

Conclusions

The pollution index model proposed appears to be promising and proved to be a useful tool in evaluating the composite quality of heavy metal pollution of the groundwater. The index is highly useful to get the rightful conclusion of overall quality of groundwater with a systematic rating. The pollution index is also used for comparative purpose of quality characteristics at different sampling sites and also to discuss the quality criteria of a particular area in detail. The study clearly indicates that, the selected and monitored groundwater sites in the Effutu municipality is free from heavy metal pollution and therefore can be used by the inhabitants.

Recommendations

From the results of this study, it is recommended that:

- There should be regular follow-up monitoring by the Effutu Municipal Environmental Health Officers to measure the levels of heavy metals and other toxic chemicals in the groundwater periodically.
- There should be increased environmental health and sanitation education by the Effutu Municipal Assembly in these communities to arouse their quest to use groundwater as a substitute for tap water.

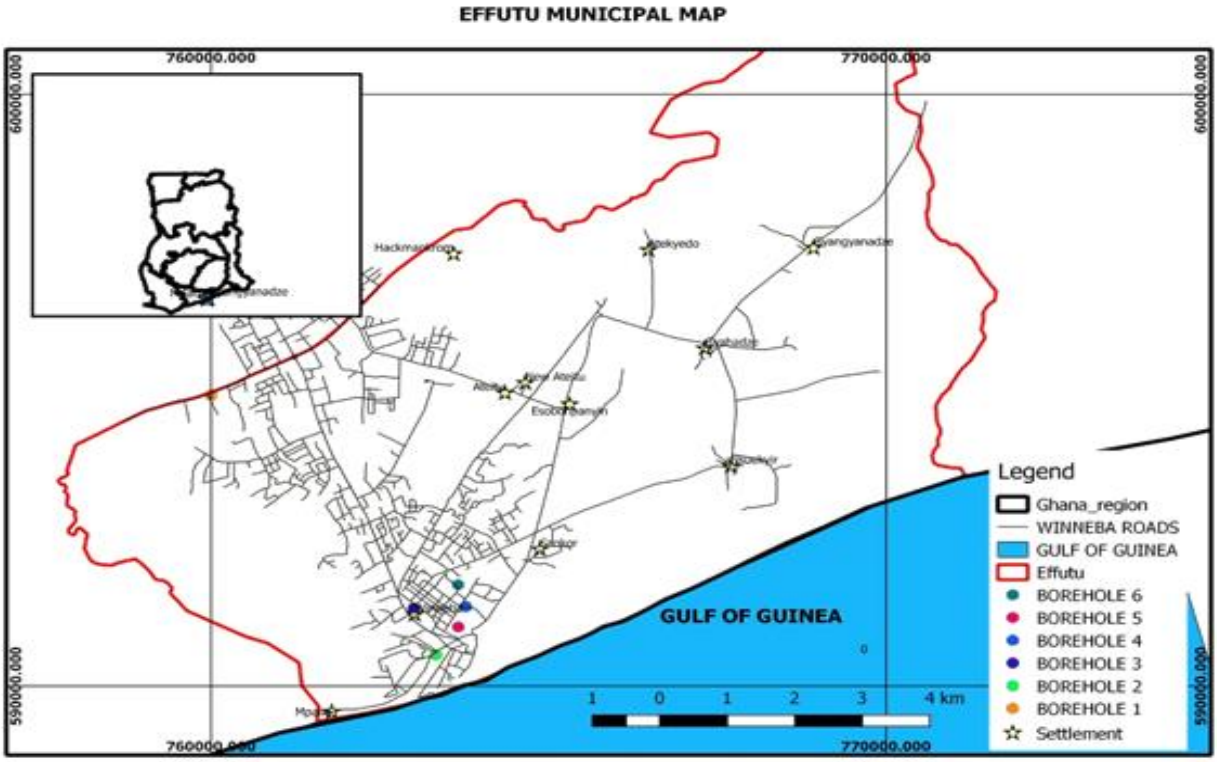

Figure 1. Map of the Study Area

Table 3. Descriptive summary statistics for heavy metals during the dry season

Parameter	Units	Min	Max	Mean	Median	Stdev	Mac[a]
Temp	^{0}C	26.7	26.8	26.78	26.8	0.041	
pH		6.78	7.41	7.15	7.21	0.228	6.5-8.5
E.C	µS/cm	740	5500	2326.5	2018.5	1643.19	1400
COD	mg/L	8	46.4	26.466	27.4	12.57	250
Cd	µg/l	<0.003	<0.003	<0.003	<0.003	<0.003	3
Co	µg/l	<0.010	<0.010	<0.010	<0.010	<0.010	1000
Fe	µg/l	7	78	33.33	19.5	30.44	200
Pb	µg/l	<0.010	<0.010	<0.010	<0.010	<0.010	1.5
Zn	µg/l	5	142	28	7	55.37	5000

EC-Electrical Conductivity; COD-Chemical Oxygen Demand

Source: Laboratory data, 2021

Table 4. Correlation matrix between the parameters during the dry season

	pH	Temp	E.C	COD	Zn	Fe	HPI_A	HPI_B
pH	1	-0.557	-0.655	-0.950**	-0.802	-0.919**	0.0920**	0.897*
Temp		1	0.242	0.758	0.212	0.424	-0.424	-0.330
E.C			1	0.681	0.946**	0.494	-0.497	-0.491
COD				1	0.748	0.811	-0.812*	-0.761
Zn					1	0.725	-0.728	-0.734
Fe						1	-1.000**	-0.995**
HPI_A							1	0.995**
HPI_B								1

Source: Laboratory data, 2021

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

HPI_A - Heavy metal pollution index with zero concentration for metals not detected during the dry season

HPI_B - Heavy metal pollution index with limit of detection of the instrument for metals not detected during the dry season

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