International Journal of Science and Technology Volume 5 No. 12, December, 2016

Physicochemical Properties and Levels of Heavy Metals in Selected Rivers within the Kumasi Metropolis of Ghana

Michael Baah Mensah[1], Nathaniel Owusu Boadi[1], Frimpomah Baa-Poku[2], David Dotse Wemegah[3], Mercy Badu[1], Selina Ama Saah[1] and Bernard Osei-Dei.

[1]Department of Chemistry, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.
[2]Department of Environmental Management and Technology, Koforidua Polytechnic, Koforidua, Ghana.
[3]Department of Physics, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

ABSTRACT

The quality of water from the Wiwi River (WR) and Sisan River (SR) in the Kumasi metropolis was investigated. The quality of the water was assessed by determining the physicochemical parameters such as, temperature, total dissolved solids (TDS), conductivity, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD) and chemical oxygen demand (COD), and heavy metals (Manganese (Mn), Iron (Fe), Copper (Cu), Zinc (Zn) and Lead (Pb)). The heavy metals concentrations were determined with the Flame Atomic Absorption Spectrometer (AAS). The temperature ranged from 22 – 29 ^{o}C and pH from 7.38 – 7.58. The TDS, conductivity and turbidity ranged from 118 – 485 mg/l, 235 – 920 µS/cm and 17.16 – 485 ntu respectively. The DO, BOD and COD concentrations ranged from 1.73 – 7.12 mg/l, 15 – 126 mg/l and 33 – 286 mg/l respectively. The concentrations of Mn, Fe, Cu, Zn and Pb in the rivers ranged from 0.036 – 0.191 mg/l, 0.273 – 0.521 mg/l, 0.274 – 0.51 mg/l, 0.048 – 0.104 mg/l and 0.018 – 0.098 mg/l respectively. Mn, Fe, Cu and Zn concentrations in the rivers were below the World Health Organization (WHO) recommended values. However, the concentrations of Pb in the rivers were above the WHO threshold. The highest Pb concentration was found in the Sisan River whilst the lowest was found in the Wiwi River. The quality of water from the rivers under study was found to be below standard and the high concentrations of lead pose serious health risks to residents who rely on these rivers as their sources of drinking water.

Key Words: *Heavy Metals, Physicochemical Properties, River, Wiwi, Sisan*.

1. INTRODUCTION

Pollution of water bodies has become a serious concern in Ghana since the majority of the population without access to piped water depend on them for their daily activities. Many research groups have therefore directed their attention to the assessment of the quality of water major water bodies in Ghana (Malik et al., 2014; Armah et al., 2010; Akoto et al., 2008; Cornish et al., 1999). Akoto, et al., (2008) worked on the water quality and heavy metals (Zn, Cu, Mg, Pb and As) pollution in four major water bodies namely Owabi, Akyeampomene, Pumpunase and Sukobri which feed the Owabi reservoir in Kumasi. Their study identified the activities of residents in those areas as the major source of water pollution and thus, recommended that human activities in those areas should be controlled. Fianko et al., (2007), determined heavy metal pollution in the Iture estuary, a major recreational site in the Central Region of Ghana and found that the water contains pre-occupying pollution levels of Cd, Zn, Pb and Se. This river has Kakum and Sorowie rivers that flow through urbanized and industrialized area as its main tributaries. The study pointed out the Sorowie River to be the major source of contamination to the Iture estuary, which may pose a threat to terrestrial and aquatic ecosystems. Donkor, et al., (2005) studied the heavy metals in sediments in the Pra River basin as a result of gold mining activities in the area. The study identified Hg, Al, Fe, As, Pb, Cu, Cr, Ni, Mn, Co, V and Zn to be present in the sediment but stated that high levels of Cu and Ni co-varied significantly with Al that suggested that the source might be a natural source. From these studies, it could be noted that the major sources of water contamination are from anthropogenic activities.

Metals such as Mn, Cr, Co, Cu, Fe and Zn are trace elements essential for biochemical processes in humans, animals and plants (Akoto et al., 2008; Kohl & Medlar, 2006). In spite of the enormous biochemical importance of these metals, they could be detrimental to life processes if their intake levels are not monitored. Biochemically, Mn serves as activator of several enzymatic activities involving enzymes such as hydrolase, kinases, decarboxylases and transferases (Yu et al., 1997). In addition, intake of Mn into the central nervous system in individuals having deficiency in Fe has been reported (Crossgrove & Zheng, 2004; Roth & Garrick, 2003). However, Mn toxicity in water has been linked to neurological and behaviour symptoms (Kohl and Medlar, 2006). Cr becomes toxic depending on its oxidation state and level of dose. Cr^{3+} and Cr^{6+} are thought to be of biological significance. Cr^{3+} is an essential dietary mineral whilst Cr^{6+} is carcinogenic (Yu et al., 2008; Guertin, 2004). Co is an important metal for the production of red blood cells in humans and animals. However, Faroon *et al.*

(2004) linked lung related diseases such as asthma, pneumonia and wheezing in people working with cobalt-tungsten carbide. Ashish *et al*. (2013) reported that Cu is vital for physical and mental health but at high levels, it deposits in the liver, disrupts the liver's normal function leading to adverse effect on the nervous system, reproductive system, adrenal function, connective tissue and learning ability of new born babies. Fe, though useful in most biological systems, has been classified as a leading cause of unintentional poisoning deaths in children less than 6 years of age (Abretsen, 2006). Nriagu, (2007) also associated long-term excessive intake of Zn to diseases such as sideroblastic anaemia, hypochromic microcytic anaemia, leukopenia, lymphadenopathy, neutropenia, hypocupraemia and hypoferraenia.

Historically, the major source of lead (Pb) poisoning in Ghana has been related to vehicular combustion of leaded fuel emissions (Ankrah et al., 1998). A recent source of lead poisoning in Ghana was reported in 2013 to be Pb paints on toys, furniture, objects and surfaces imported into the country. According to the research report released in 2013 by the United Nations (UN), enamel decorative paints on toys, furniture and objects found in countries such as Argentina, Azerbaijan, Chile, Cote d'Ivoire, Ethiopa, Ghana, Krygyzstan, Tunisia and Uruguay contained high levels of lead. Unfortunately, many of these painted toys and objects end up in water bodies due to poor municipal solid water management. Some studies have shown that exposure to Pb has adverse effect on maternal and infant health which include fertility, hypertension and infant neurodevelopment (Brown & Margolis, 2012). Flora *et al*. (2012) also stated that Pb has detrimental effect on the hematopoietic, renal, reproductive and central nervous systems. Pb is also classified as carcinogenic (Brown & Margolis, 2012). Because of the detrimental effect of Pb and other related heavy metals on public health and animal lives, their presence and concentrations in water bodies meant for drinking and other human activities require serial monitoring in order to establish trends and awareness.

Access to safe water is essential to good health. Provision of portable water in urban areas of Ghana such as Kumasi remains a challenge as human population and urbanization increases (Akoto et al., 2008). Ashanti region population increased from about 3.6 million in 2000 to 4.78 million in 2010 (Ghana Statistical Service, 2013). Majority of the population are concentrated in Kumasi due to urbanization. Maoulidi (2010) reported that 66.2 % of Kumasi residents had access to piped water in 2000 and 80 % had access in 2008. Maoulidi (2010) also estimated that 73 % of the population in Kumasi would access piped water in 2015. This implies that there are some residents (27 %) in Kumasi lacking piped water. Majority of such residents may rely on water bodies in their vicinity for their daily activities. However, rivers in the Kumasi metropolis are in a deplorable state and the quality of water is far below Environmental Protection Agency (EPA) and WHO drinking water requirements due to urbanization and poor management of municipal solid waste. Thus, this work seeks to determine the physicochemical properties and levels of heavy metals such as Mn, Fe, Pb, Cu and Zn in water samples from Wiwi and Sisan Rivers in the Kumasi metropolis.

2. MATERIALS AND METHODS

2.1. Study Area

Kumasi is the capital city of Ashanti Region of Ghana. It is located about 270 km north-west of Accra, the capital city of Ghana. The metropolis lies approximately between 636,000 to 671,000 east and 728,000 to 756,000 north projected in the Universal Transverse Mercator, (WGS84) zone 30N and located on portions of the Survey of Ghana 1: 50,000 scale series topographic maps sheets 0602A4 and 0602C4. Kumasi functions as a nodal town as roads from the north, south, east and western parts of the country pass through it. Kumasi features a tropical wet and dry climate, with relatively constant temperatures throughout the course of the year.

2.1.1. Wiwi River (WR)

The Wiwi River (WR) is a typical example of an inland water body in Kumasi. It takes its source from mountains near Aboabo Nkwanta and flows for about 13 miles southwest towards Abirem and Weweso. It passes through the Kwame Nkrumah University of Science and Technology (KNUST) campus to join the Sisan River (SR) at Atonsu (figure 1). WR serves various purposes including recreational and agricultural activities and a source of household water in the communities it passes.

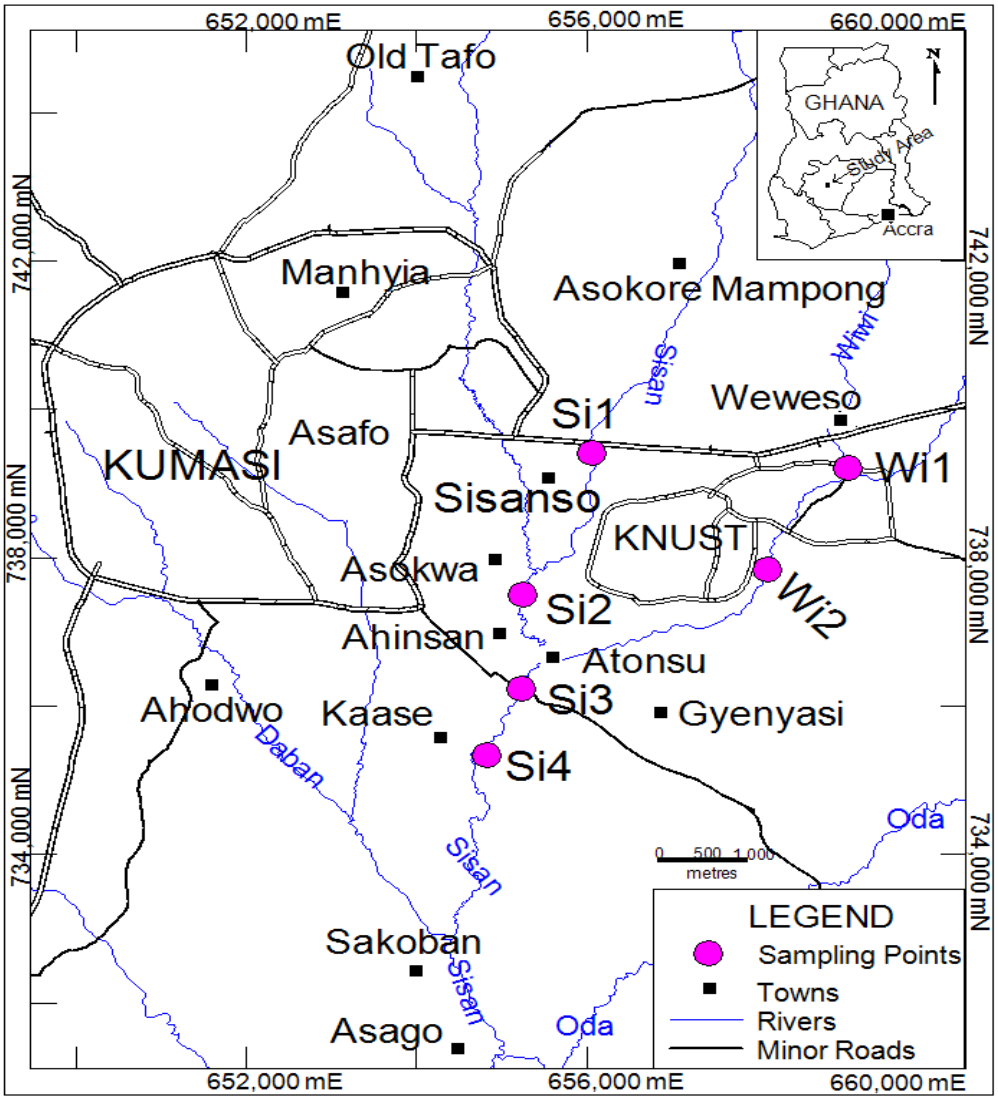

Figure 1: Map of study area projected in UTM (WGS84) Zone 30N showing the showing the sampling.

2.1.2 Sisan River (SR)

The Sisan River (SR) starts from Mamponteng in the Kwabre district of Ashanti Region. It passes through Kumasi and then joins the Oda River. SR meanders through Asokore Mampong, Sisanso, Asokwa, Ahinsan through to Atonsu where it meets the WR (figure 1). It then passes through the Kaase industrial area and joins the Daban River (DR) at Sakoban. It finally joins the Oda River near Asago. WR and DR are the major tributaries of SR. Geologically, the area falls within the Birimian metasediments of the Kumasi Basin. The lithostratigraphic units in the area are mainly weathered saprolite layer of 22 to 30 m thick with overlying the Basin type granitic bedrock that is an outcrop of some parts of the area. Along the banks are fine sandy clay deposits eroded from upstream. Downstream, rural and peri-urban communities rely on it for domestic water supply and for watering livestock. For the purpose of this study, the SR was divided into two sections: SR flowing through Sisanso to Ahinsan was termed as SRa and SR flowing from Atonsu to Kaase industrial area was termed SRb. This division was done because the catchment areas where SRa and SRb pass are significantly different in terms of anthropogenic activities. Land use on the banks of SRa is mainly arable and pastoral agriculture, with some urban settlements and slumps. SRb receives untreated wastewater from two breweries, a soft drink factory, a teaching hospital, an abattoir, wood processing plants, outfall pipes from run-down sewage works and the city's refuse.

2.2. Sampling

The water samples were collected in polyethylene bottles. Prior to sample collection, the bottles were cleaned with detergent and distilled water followed by soaking in nitric acid (2 M) over night and then rinsed several times with double distilled water and dried. Two samples were collected from WR and four samples from SR summing up to six samples shown on the map above. From WR, samples were taken from the KNUST Botanical garden (close to the Accra-Kumasi road) and KNUST campus 'Mecca' road bridgehead and labelled Wi1 and Wi2 respectively. From SRa, sample (Si1) was taken at the Sisanso Head Bridge and sample (Si2) at Ahinsan. From SRb, samples Si3 and Si4 were taken from the Atonsu Head Bridge and Kaase industrial area Head Bridge respectively. The samples were taken 10 cm below the water surface, stored in a cool ice-chest and transported to the laboratory for analyses.

2.3. Physicochemical properties of water samples

The temperature, turbidity, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) were determined following standard methods outline in APHA (1992).

2.4. Sample preparation for heavy metal analysis with AAS

All glassware were cleaned by soaking in detergent solution overnight after which they were rinsed with distilled water and then soaked in 10 % HNO_3 solution overnight. They were then rinsed with distilled water and dried. About 100 ml of each water sample transferred into 250 ml beaker and 5 ml of concentrated HNO_3 added. The resultant mixture was heated on hotplate in fumehood until the volume reduced to about 20-30 ml. Digestion was continued by heating and adding of HNO_3 until a light coloured and clear solution was obtained. The solution was cooled, filtered with a whatman No. 41 filter paper into a 50 ml volumetric flask, and made up to the mark. A blank solution was prepared with the same procedure with the sample. Analysis for concentrations of Mn, Fe, Pb, Cu and Zn was done with Atomic Absorption Spectrometer (AAS) in replicate and the standard deviations determined.

2.5. Statistical Analysis

The results were reported as mean ± standard deviation. All statistical analysis were done using both Microsoft Excel (2010 Edition) and Origin statistical software packages. The relationships between the heavy metal concentrations and physicochemical properties of the rivers were determined with Pearson correlation coefficients at 0.05 significance level.

3. RESULTS AND DISCUSSIONS

Table 1 shows the physicochemical properties of the water samples from the WR, SRa and SRb in the Kumasi Metropolis. The temperature of the rivers ranged within 22 – 29 ^oC that was similar to 22.1 – 27.48 ^oC reported by Akoto *et al*. (2008) who worked on water quality of streams serving the Owabi reservoir in Kumasi. Also the pH (7.35 – 7.58) of the rivers were within the WHO standard and comparable to 6.8 – 7.7 reported by Fianko *et al*. (2007) on water from Iture estuary in Central Region of Ghana. The pHs were quite high compared to the minimum WHO standard value and reflect the presence of dissolved carbonates, bicarbonates and other basic compounds in the rivers. The SRa was less alkaline compared to the WR and SRb. The average values of the total dissolved solids (TDS) were 124 mg/l, 172 mg/land 459.5 mg/l for WR, SRa and SRb respectively.

Table 1: Physicochemical properties of water samples from Wiwi River and Sisan River (SRa and SRb) in Kumasi

Parameters	Wi1	Wi2	Si1	Si2	Si3	Si4	WHO (2003)
Temperature (°C)	28	29	23	22	23	23	-
pH	7.43	7.48	7.35	7.38	7.58	7.45	6.5-8.5
TDS (mg/l)	118±0.58	130±0.58	135±0.58	210±0.58	485±0.58	434±0.58	500
Conductivity (uS/cm)	235±1.00	288±0.58	261±1.00	298±1.00	920±1.00	868±0.58	500
Turbidity (ntu)	17.16±0.01	18.65±0.01	496±1.00	546±1.00	485±0.58	434±0.58	5
DO (mg/l)	6.61±0.01	7.12±0.01	4.97±0.01	5.41±0.01	1.93±0.01	1.73±0.01	>5
BOD (mg/l)	15±0.58	20±0.58	30±0.58	42±0.58	126±1.00	100±0.58	10
COD (mg/l)	33±1.00	46±1.00	47±1.00	57±1.00	286±1.00	233±1.00	10

The average TDS figures revealed that WR had less dissolved substances while SRb had the highest dissolved substances. The conductivity of the water on average was 261.5 µS/cm for WR, 279.5 µS/cm for SRa and 894 µS/cm for SRb. Karikari and Ansa-Asare (2004), determined the turbidity of the Densu River to be within the range 239 – 402 µS/cm. This is similar to that found for WR and SRa. The conductivity values of WR and SRa were below the WHO recommended standard of 500 µS/cm while that of SRb was higher than it.

From the conductivity and TDS results, it could be revealed that SRb contains the highest amount of inorganic dissolved solids such as chloride, nitrate, sulphate, sodium, magnesium, calcium, iron and aluminium ions. This result may be because the vicinity of SRb is characterized by industries and institutions such as breweries, soft drink factory, hospital, abattoir and wood processing located in the catchment area of the river. However, the turbidity (which relates to water transparency) on average was 459.5 ntu for SRb, 521 ntu for SRa and 17.9 ntu for WR. The turbidity of SRb was 11.8 % lower than that of SRa; implying that SRa was more turbid compared to SRb. The increasing order of transparency was WiR > SRb > SRa. The high turbidity of SRa may be as a result of erosion of clay deposits from upstream and agricultural activities in the catchment. In addition, it may be due to the presence of microbial activities in the river such as algae, plankton, microbes and other substances. The low turbidity of WR could be link to the low anthropogenic activities in its catchment area. The turbidity results were comparable to 21.1 – 818 ntu range recorded by Akoto *et al*. (2008). The turbidity values of all the three rivers were far above the WHO standard of 5 ntu.

Dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD) relate to dissolved oxygen required for breaking down of organic matter in water bodies. WR on average recorded the highest DO value of 6.9 mg/l whilst SRb on the other hand recorded the lowest DO of 1.83 mg/l. Karikari and Ansa-Asare (2004) reported a similar DO value between 6.6 – 7.16 mg/l for Densu River. SRb on the average recorded the highest BOD value of 113 mg/l whilst WR recorded the lowest value of 17.5 mg/l. Obiri-Danso *et al*., (2005) worked on the health related microbiology of the SRb and reported a mean range of BOD of 4 – 419 mg/l along the course of the river and it compares with those obtained in this work. SRa recorded BOD range of 30 – 42 mg/l. The COD measurements also showed that SRb had the highest COD ranging between 233 – 286 mg/l, followed by SRa with 47 – 57 mg/l and the lowest of 33 – 46 mg/l for WR. All the rivers under investigation recorded DO, BOD and COD values which were above the WHO standard values. Again, the DO, BOD and COD values recorded for SRb showed that there were high levels of biological organism activities in the river due to its high composition of organic matter residues because of industrial activities in the catchment.

3.2. Heavy Metals Concentrations

Figure 2 shows the comparison of average heavy metals concentrations in the WR, SRa and SRb. The Mn concentrations in all the three rivers were below 0.2 mg/l. WR had the highest average concentration of Mn of 0.126 mg/l and the lowest of 0.059 mg/l was recorded for SRa. SRb recorded an average Mn concentration of 0.015, which was below 0.1 mg/l. Akoto *et al*. (2008) reported a similar range of Mn concentration of 0.01 – 0.24 mg/l in the streams serving the Owabi Reservoir in Kumasi. Fe and Cu were the dominant heavy metals found in the rivers under investigation. Fe concentration in the SRa was on the average 0.47 mg/l compared to 0.38 mg/l and 0.28 mg/l recorded for SRb and WR respectively. SRb was found to contain the highest level of Cu of 0.49 mg/l, which may be due to waste materials containing high concentrations of Cu from the hospital and industries in the catchment area. SRa and WR were found to contain Cu concentrations of 0.38 mg/l and 0.31 mg/l. WR and SRa contain similar concentrations of Zn of 0.058 mg/l whilst SRb recorded the highest concentration of 0.094 mg/l. Levels of Mn, Fe, Cu and Zn in the rivers were below the WHO recommended values by 19 – 98 %.

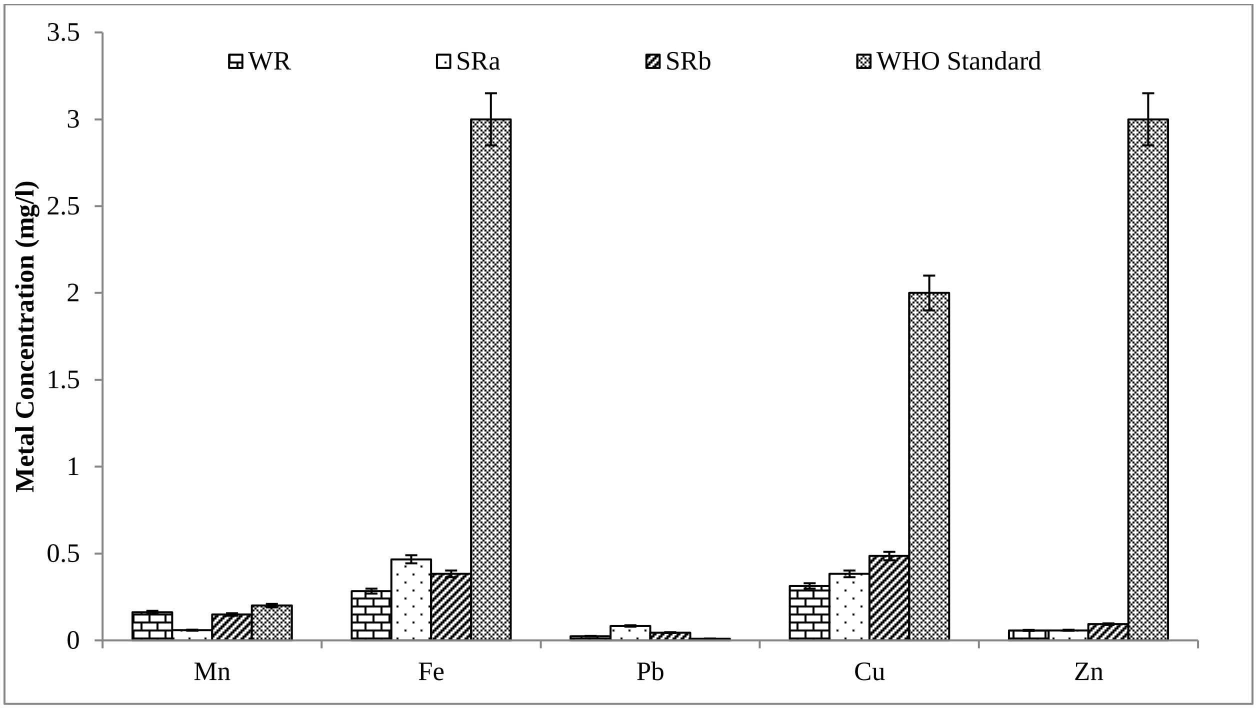

Figure 2: Heavy metal concentrations in Wiwi River and Sisan River (SRa and SRb) in the Kumasi Metropolis compared to WHO recommended values.

However, the average concentration of Pb in the rivers were between 0.025 – 0.083 mg/l which are higher than 0.01 mg/l recommended value by WHO. SRa recorded the highest Pb concentration of 0.083 mg/l, SRb recorded 0.045 mg/l and the lowest was 0.025 mg/l recorded for WR. SRa was highly polluted with Pb. These high concentrations of Pb in the rivers are alarming, since it poses serious health danger to residents who use the rivers as drinking water without any proper purification. Table 2 compares the heavy metal concentrations found in the present work to similar works done on other water bodies in Ghana.

Table 2: Comparison of heavy metals concentrations in some water bodies in Ghana

Description Water body	Fe (mg/l)	Mn (mg/l)	Cu (mg/l)	Zn (mg/l)	Pb (mg/l)	Reference
Wiwi River	0.273-0.294	0.133-0.191	0.274-0.353	0.048-0.067	0.018-0.031	*Present work*
Sisan River (SRa)	0.467-0.521	0.036-0.081	0.383-0.426	0.058-0.097	0.068-0.098	*Present work*
Subin River (SRb)	0.353-0.413	0.109-0.189	0.459-0.512	0.083-0.104	0.035-0.055	*Present work*
Densu River	0.614-1.19	0.264-0.337	0.028-0.274	0.014-0.10	0.005-0.039	*Karikari and Ansa-Asare, 2004*
Owabi Reservoir	0.01-1.69	0.01-0.24	0.01-0.08	0.01-0.3	0.01-0.03	*Akoto et al., 2008*
Iture Estuary	-	-	-	0.4-2.45	0.020-0.075	*Fiako et al., 2006*
Ground water	0.87	0.031	-	0.028	-	*Ackah let al., 2011*

Possible relationships between metal-metal, metal-physicochemical properties (TDS, Conductivity, Turbidity, DO, BOD and COD) and physicochemical property- physicochemical property were investigated using the Pearson correlation coefficient, r, at 0.05 significant level for all the rivers (Table 3). Mn had negative correlations with Fe and Pb and positive correlations with Cu and Zn. This observation is similar to that reported by Akoto *et al*., (2008). Mn also had positive correlations with all the physicochemical properties determined with the exception of turbidity and dissolved oxygen. All other correlations between metals were positive with Fe having a significant correlation coefficient of 0.976 with Pb and Cu of 0.899 with Zn. These significant correlations of metals are indicative of a common source of pollution in the rivers. With the exception of Pb that correlated negatively with conductivity and COD and Mn with turbidity, the metals correlated positively with the physicochemical properties except DO, which showed negative correlation with all the metals. It can therefore be inferred that Dissolved oxygen (DO) is reduced when levels of heavy metals increase in rivers. Cu and Zn especially showed significant positive correlations with the physicochemical properties determined except DO. Among physicochemical properties however, there were positive correlations except with DO. This indicates that increase in TDS, EC, Turbidity, BOD or COD tends to decrease dissolved oxygen in the rivers. Conductivity had significant positive correlations with TDS. BOD and COD with correlation coefficients of 0.987, 0.978 and 0.995 respectively. TDS also had significant correlation coefficient of 0.988 with COD.

Table 3: Pearson's correlation of the heavy metals and physicochemical properties

	Mn	Fe	Pb	Cu	Zn	TDS	Cond.	Turb.	DO	BOD	COD
Mn	1.000										
Fe	-0.599	1.000									
Pb	-0.523	0.976	1.000								
Cu	0.098	0.531	0.453	1.000							
Zn	0.228	0.543	0.551	0.899	1.000						
TDS (mg/l)	0.287	0.140	0.032	0.861	0.746	1.000					
Cond. (uS/cm)	0.322	0.006	-0.116	0.790	0.634	0.987	1.000				
Turb. (ntu)	-0.520	0.890	0.791	0.777	0.663	0.524	0.425	1.000			
DO (mg/l)	-0.057	-0.273	-0.130	-0.897	-0.677	-0.948	-0.938	-0.665	1.000		
BOD (mg/l)	0.263	0.190	0.072	0.877	0.745	0.263	0.978	0.564	-0.952	1.000	
COD (mg/l)	0.343	0.050	-0.071	0.817	0.667	0.988	0.995	0.450	-0.936	0.990	1.000

4. CONCLUSION

The quality of water from the Wiwi River and Sisan River was analyzed. The temperature range was 22 – 29 ºC whilst the pH was 7.38 – 7.58. The TDS, conductivitiy and turbidity ranges were 118 – 485 mg/l, 235 – 920 µS/cm and 17.16 – 485 ntu. SRb contained the highest amount of inorganic dissolved solids. This may be because it receives industrial effluents from industrials in the catchment area. The increasing order of water transparency was WR > SRb >SRa. DO, BOD and COD values range between 1.73 – 7.12 mg/l, 15 – 126 mg/l and 33 – 286 mg/l respectively.

All the rivers under investigation recorded DO, BOD and COD values which were above the WHO standard values. It was seen that SRb contained the highest levels of organic matter residue compared to SRa and WR. The concentrations of manganese, iron, copper, zinc and lead in the rivers ranged between 0.036 – 0.191 mg/l, 0.273 – 0.521 mg/l, 0.274 – 0.51 mg/l, 0.048 – 0.104 mg/l and 0.018 – 0.098 mg/l respectively. Manganese, iron, copper and zinc concentrations in the rivers were below the WHO recommended values by 19 – 98 %. However, the concentration of lead in the rivers was about 150 % to 730 % higher than 0.01 mg/l recommended value by WHO. The highest lead concentration was found in the Sisan River whilst the lowest was found in the Wiwi River. The quality of water from the rivers under study was found be below standard. The high concentration of lead poses serious health dangers to residents who rely on these rivers for drinking water.

Acknowledgement

The authors are grateful to the Department of Chemistry and the Water and Sanitation section of the Department of Civil Engineering, all of Kwame Nkrumah University of Science and Technology for allowing us to use their laboratory facilities.

REFERENCES

Abretsen, J., 2006. The toxicity of iron, an essential element. *Toxicology Brief, Veterinary Medicine*, pp.82-90.

Akoto, O., Bruce, T.N. & Darko, G., 2008. Heavy metals pollution profiles in streams serving the Owabi reservoir. *African Journal of Environmental Science and Technology*, 2(11), pp.354-59.

Ankrah, N.A. et al., 1998. Lead exposure in urban and rural school children in Ghana. *African Journal of Health Science*, 5(1-2), pp.85-88.

APHA, 1992. *Standard methods for the examination of water and wastewater*. USA: American Public Health Association.

Armah, F.A. et al., 2010. Anthropogenic sources and environmentally relevant concentrations of heavy metals in surface water of a mining district in Ghana: a multivariate statistical approach. *Journal of Environmental Science and Health Part A*, 45, pp.1804-13.

Ashish, B., Neeti, K. & Himanshu, K., 2013. Copper Toxicity: A comprehensive study. *Research Journal of Recent Sciences*, 2(ISC-2012), pp.58-67.

Brown, M.J. & Margolis, S., 2012. Lead in drinking water and human blood lead levels in the United States. *Morbidity and Mortality Weekly Report*, 61, pp.1-10.

Cornish, G.A., Mensah, E. & Ghesquiere, P., 1999. *An assessment of surface water quality for irrigation and its implications for human health in the peri-urban zone of Kumasi.* HR Wallinford: KAR Project R7132, Report OD/TN 95.

Crossgrove, J. & Zheng, W., 2004. Manganese toxicity upon overexposure. *NMR in Biomedicine*, 17(8), pp.544-53.

Donkor, A., Bonzongo, J.J., Nartey, V.K. & Adotey, D.K., 2005. Heavy metals in sediments of the gold mining impacted Pra River basin, Ghana, West Africa. *Soil and Sediment Contamination*, 14, pp.479-503.

Faroon, O.M. et al., 2004. *Toxicological profile for cobalt*. USA: U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substance and Disease Registry.

Fianko, J.R. et al., 2007. Assessment of heavy metal pollution of the Iture estuary in the Central Region of Ghana. *Environmental Monitoring and Assessment*, 131, pp.467-73.

Flora, G., Grupta, D. & Tiwari, A., 2012. Toxicity of lead: A review with recent updates. *Interdisciplinary Toxicology*, 5, pp.47-58.

Ghana Statistical Service, 2013. 2010 Population and Housing Census. *National analytical report*.

Guertin, J., 2004. *Toxicity and health effects of chromium (all oxidation states)*. CRC Press LLC.

Karikari , A.Y. & Ansa-Asare, O.D., 2004. *Physicochemical and microbial water quality assessment of Densu river of Ghana*. Accra, Ghana: CSIR-Water Research Institute.

Kohl, P.M. & Medlar, S.J., 2006. *Occurrence of manganese in drinking water and manganese control.* Awwa Research Foundation and U.S. Environmental Protection Agency.

Malik, A., Saah, S.A. & Boadi, N.O., 2014. Physicochemical and microbial properties of sachet water in the Kumasi metropolis of Ghana. *Ghana Journal of Chemistry*, 2(1), pp.10-19.

Maoulidi, M., 2010. *A water and sanitation needs assessment for Kumasi, Ghana*. MCI Social Sector Working Paper series No. 16/2010.

Nriagu, J., 2007. *Zinc toxicity in humans.*. School of Public Health, University of Michigan, Elsevier B.V.

Obiri-Danso, K., Weobong, C.A.A. & Jones, K., 2005. Aspects of health-related microbiology of Subin, an urban river in Kumasi, Ghana. *Journal of Water and Health*, 3(1), pp.69-76.

Roth, J.A. & Garrick, M.D., 2003. Iron interactions and other biological reactions mediating the physiological and toxic actions of manganese. *Biochemical pharmacology*, 66(1), pp.1-13.

WHO, 2004. *Guidelines for drinking water quality*. 3rd ed. World Health Organisation.

Yu, D. et al., 2008. *Chromium toxicity*. Agency for Toxic Substances and Disease Registry Case Studies in Environmental Medicine.

Yu, R. et al., 1997. Activation of nitrogen-activated protein kinases by green tea polyphenols: signaling pathways in the regulation of antioxidant-responsive element-mediated phase II enzyme gene expression. *Carcinogenesis*, 18(2), pp.451-56.

