

Heavy Metal Contamination and Physico-Chemical Assessment of the Densu River Basin in Ghana

¹G.B. Hagan, ²F.G. Ofori, ³E.K. Hayford, ¹E.K. Osaie and ⁴K. Oduro-Afriyie

¹Department of Physics, University of Ghana, Accra, Ghana

²Department of Physics, Ghana Atomic Energy Commission, Kwabenya, Accra, Ghana

³Department of Earth Science, University of Ghana, Accra, Ghana

⁴Central University College, Miotso, Tema, Ghana

Abstract: Physico-chemical and Trace metal analyses were carried out on water and sediment samples from the Densu River in Ghana to ascertain the water quality. The pH values ranged from 6.55 to 7.33 and were within the natural background level of 6.5-8.5. The Total Dissolved Solids (TDS) values ranged from 67.1 to 113.0 mg/L and were below the World Health Organization (WHO) recommended value of 1000 mg/L. The Electrical Conductivity (EC) values ranged from 150.3 to 223.0 μ S/cm and were below the acceptable value of 350 μ S/cm for unpolluted river. The salinity values were generally insignificant. The Atomic Absorption Spectrometry (AAS) technique was used for the trace metal analysis. The elemental analysis was done for Cd, Cu, Fe, Hg, Mn, Ni and Zn. The analysis gave Fe (1.590-6.090) mg/L, Mn (0.039- 0.661) mg/L and Zn (0.005-0.021) mg/L in the water samples. The concentrations of Cd, Cu, Hg and Ni were below their respective detection limits for the analytical method used. The elemental concentrations in the soil sediments were Cu (6.0-46.5) mg/kg, Fe (11,200-47,800) mg/kg, Mn (143-1488) mg/kg and Zn (6.5-108.0) mg/kg. Cd, Hg and Ni levels were below their respective detection limits. Enrichment factor computation for the soil sediments revealed that there could be moderate anthropogenic contributions to the levels of Mn and Zn in the sediments.

Key words: Atomic absorption spectrometry, electrical conductivity, elemental analysis, enrichment factors, pH, physico-chemical analysis, total dissolved solids

INTRODUCTION

The pollution of land, water and air has been a global concern. Ghana with a population growth rate of 4.1% for the year 2010 (Indexmundi, 2011) is battling with this side effect from urbanization, industrialization and population growth. Agro-industries along the banks of the Densu River use the river as a source of water for their cultivation and so, the pollution of the river is expected. River Densu is the main source of water for the Accra metropolis and parts of the Eastern region of Ghana.

The Densu River basin lies between latitudes 5°30' N to 6°20' N and longitude 0°10' W to 0°35' W (Fig. 1) and shares its boundary with the Odaw and Volta basins to the east and north, respectively, the Ayensu and Okrudu to the west and the Birim basin to the northwest. The Densu River forms part of the coastal river basin of Ghana and it is used extensively as a source of water supply to both Eastern and Greater Accra regions. It covers a total drainage area of 2564.1 km² and has a length of 120 km. With a drainage of 0.047 (Debrah, 1999) it passes through the Eastern Region and portions of Greater Accra Region. It is also the main source of mudfish and tilapia for the communities along the river. Anthropogenic activities

introduce both organic and inorganic pollutants in the form of heavy metals and pesticides respectively into the water, sediment and biota of the basin. Some heavy metals like Pb, As, Cd and Hg even at low concentrations are toxic to life.

The main tributaries of River Densu include rivers Adaiso, Nsakyi, Daboro, and Kuia, as shown in Fig. 1. The recipient downstream of the Densu River is the Weija reservoir which is one of the two main sources of water supply for the city of Accra. River Densu however, serves the communities along its catchment midstream to upstream where the water receives little or no treatment at all. 95% of the basin is underlain by crystalline rocks, comprising five formations, namely Birimian, super group intruded by Granites, Togo series, and Dahomeyan and Accraian sediments (Amuzu, 1975). With the exception of Accraian, the rest are Precambrian (Fig. 1). At the source, it flows over metamorphosed lava, phyllites, schists tuffs and grey wacke. The dominant soils are ochrosols, with patches of gleisols and lithosols (Amuzu, 1975). These geogene factors control the downstream evolution of the river chemistry. The Densu River serving as a wide link among the villages and towns between Tafo and Accra is one of the largest terrestrial

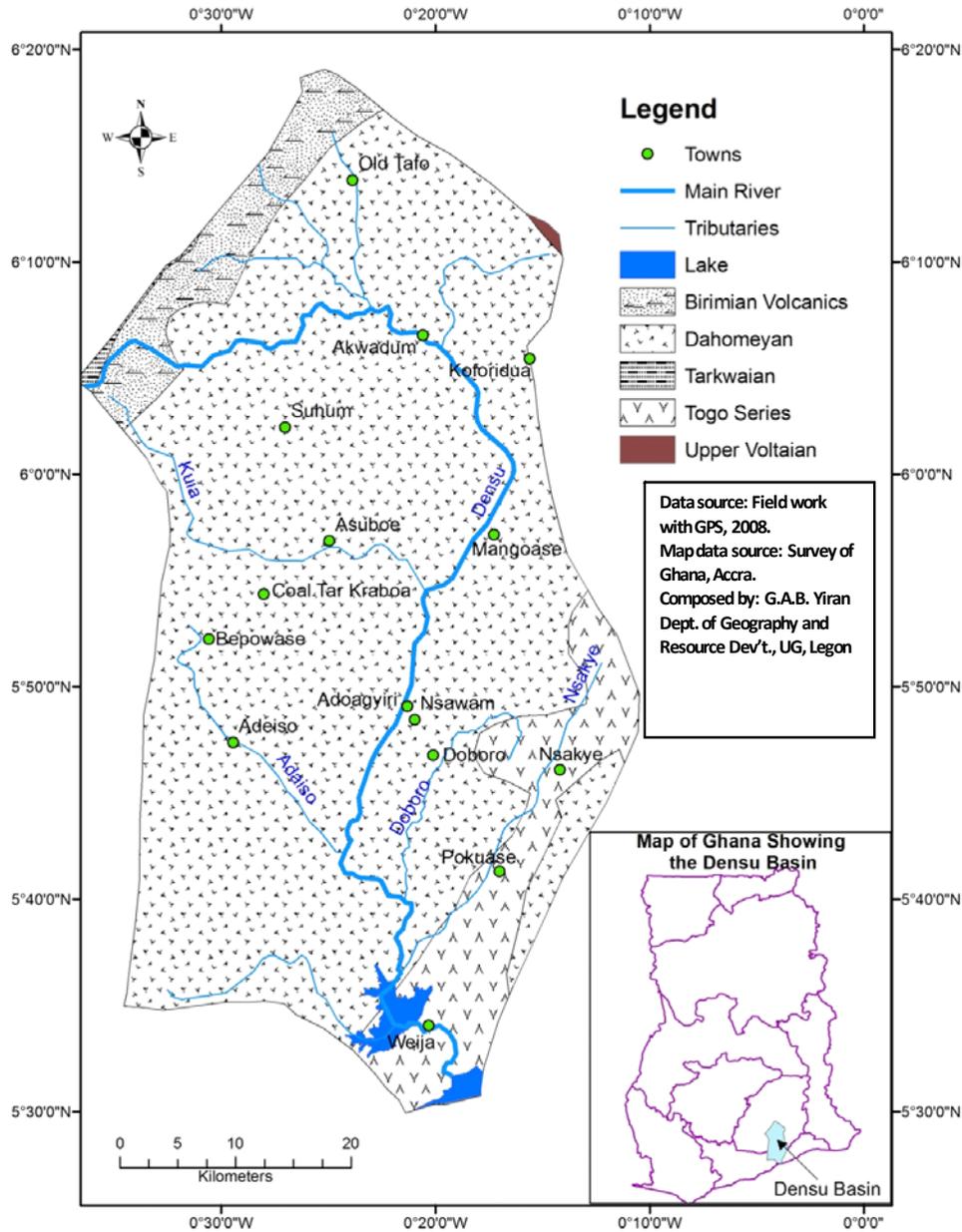


Fig. 1: A Geological map of the Densu basin showing the Densu and the formations of the basin. On the south of it is the Weija lake with a salt weaning lagoon at the south-east, (Modified after Geological Survey of Ghana, Accra)

fresh water reservoir supplying Accra with drinking water. It plays an important role in the ecology, history and economy of the industrialized northeastern part of Ghana.

The basin falls under two distinct climate zones characterized by two rainfall regimes with different intensities (Dickson and Benneh, 1980). The basin has by two rainfall maxima in a year, with the mean annual rainfall varying from about 900 to 1200 mm. The first

rainfall season starts from May and ends in June and the second rainfall season starts from September and ends in October. The highest mean monthly temperature of about 30°C occurs between March and April, and the lowest of about 26°C in August (Amuzu, 1975).

The total population within the Densu River basin is estimated to be about 1.2 million people (2000 census). The main economic activity within the drainage basin is cash crop farming, but within its banks we have the

Table 1: Mean values of *in-situ* measurements performed on the water samples

ID	Conductivity ($\pm 0.5\%$ $\mu\text{S}/\text{cm}$)	TDS ($\pm 0.5\%$ mg/L)	Salinity ($\pm 0.5\%$ mg/L)	pH ± 0.01
S _R	213.0	97.9	0	6.70
AK _W	150.3	67.1	0	5.93
AK _{str}	203.0	91.6	0	6.33
AK _{S,R}	212.0	97.5	0	6.97
KAN _R	208.0	95.8	0	6.56
DF _R	209.0	95.5	0	6.92
DF _{BH}	725.0	336.0	0.3	6.54
AY _R	206.0	94.8	0	6.83
KA _W	210.0	97.2	0	6.90
KA _D	223.0	113.0	0	6.55
KA _{BH}	1606.0	76.1	0.4	6.55
AS _R	196.6	90.5	0	7.33
AD _R	194.9	89.1	0	7.09

cultivation of vegetables. There is also the rearing of livestock and fishing.

With the ever-expanding population along the Densu basin, there is the need for proper conservation and efficient utilization of freshwater bodies for sustainable development. This is necessary because there has been accelerated deterioration of water quality within the basin because of increased domestic, municipal and agricultural activities. Effluent discharge, urbanization and deforestation are the main causes of environmental degradation within the catchments of the Basin.

As a result of these anthropogenic factors and geogene influences on the River Densu (as source of drinking water), it becomes imperative that regular reliable physico-chemical properties and levels of inorganic pollution of the Densu River is investigated. The sampling sites were selected along the course of the Densu River and its tributaries to study the possible agricultural influences on the water quality.

It is the objective of this work to investigate the inorganic pollutants levels and physico-chemical properties of the Densu River to ascertain its water quality.

MATERIALS AND METHODS

Sampling: Samples were collected monthly in the year 2008 from all the sampling points along the Densu river which takes its source from the Eastern region and enters the sea in the Greater Accra region of Ghana. Water and sediment samples were taken from the same location at each sampling site. A total of 216 water samples and 180 sediment samples were collected over a nine (9) months period. Sampling was carried out at the following communities (Fig. 2). Sakyerkrom (S_R from the River), Akraman (AK_W from a dug well, and AK_R from the river), Kankafiona (KAN_R from the river), Dome Faase (DF_R from the River, and DF_{BH} from a bore hole), Ayitekoto (AY_R from the river), Kojo Ashong (KA_W from the river where the dwellers do their washing and bathing, and KA_D from the river where the dwellers drink from, and KA_{BH} from a bore hole), Ashalaja (AS_R from the River) and Ayikaidoblo (AD_R from the River).

Water samples were collected at depths of 20-30 cm from the river surface directly into 1litre pre-conditioned polyethylene bottles. Two sets of water samples were collected at each sampling point. One set was used for *in-situ* measurement of pH, Total Dissolved Solids (TDS), Electrical Conductivity and Salinity using a portable meter (Table 1). The other set was acidified with 1% nitric acid solution to keep the metal ions in the dissolved state. The samples were kept over ice in an ice chest and transported to the laboratory for the elemental analysis. The samples were kept in a refrigerator at about 4°C until analysis was performed.

Similarly, sediments were also taken from depths of 5-10 cm below the river bed using a plastic trowel and pre-cleaned polyethylene bags.

Sample preparation and analysis: An Atomic Absorption Spectrometer (UNICAM 969) was used for the elemental analysis of both the water and sediment samples.

An amount of 2 mL of concentrated HNO₃ (65%) was added to 0.2 g of water sample in a Teflon tube, and then placed in a bomb. The bomb was placed on a hot plate and digested for 7 h at 150°C. The digested sample was allowed to cool to room temperature and transferred into polypropylene graduated tubes. The content was diluted with distilled water to give 25 mL for aspiration. Two other replicates were prepared out of the sample. The same process was repeated for all the water samples. Sediment samples devoid of debris were dried and ground to very fine powder. The same digestion process carried out on the water samples was repeated for the powdered sediment samples.

A blank was prepared using only concentrated HNO₃ and analyzed for the concentrations of the elements under study. The determined concentrations were subtracted from those of the water and sediment samples to give the actual concentration of each element present.

A summary of the trace metal concentrations in the water and soil sediment samples are shown in Table 2 and 3.

Validation of the analytical method: Two standard reference materials - IAEA 356 from the National

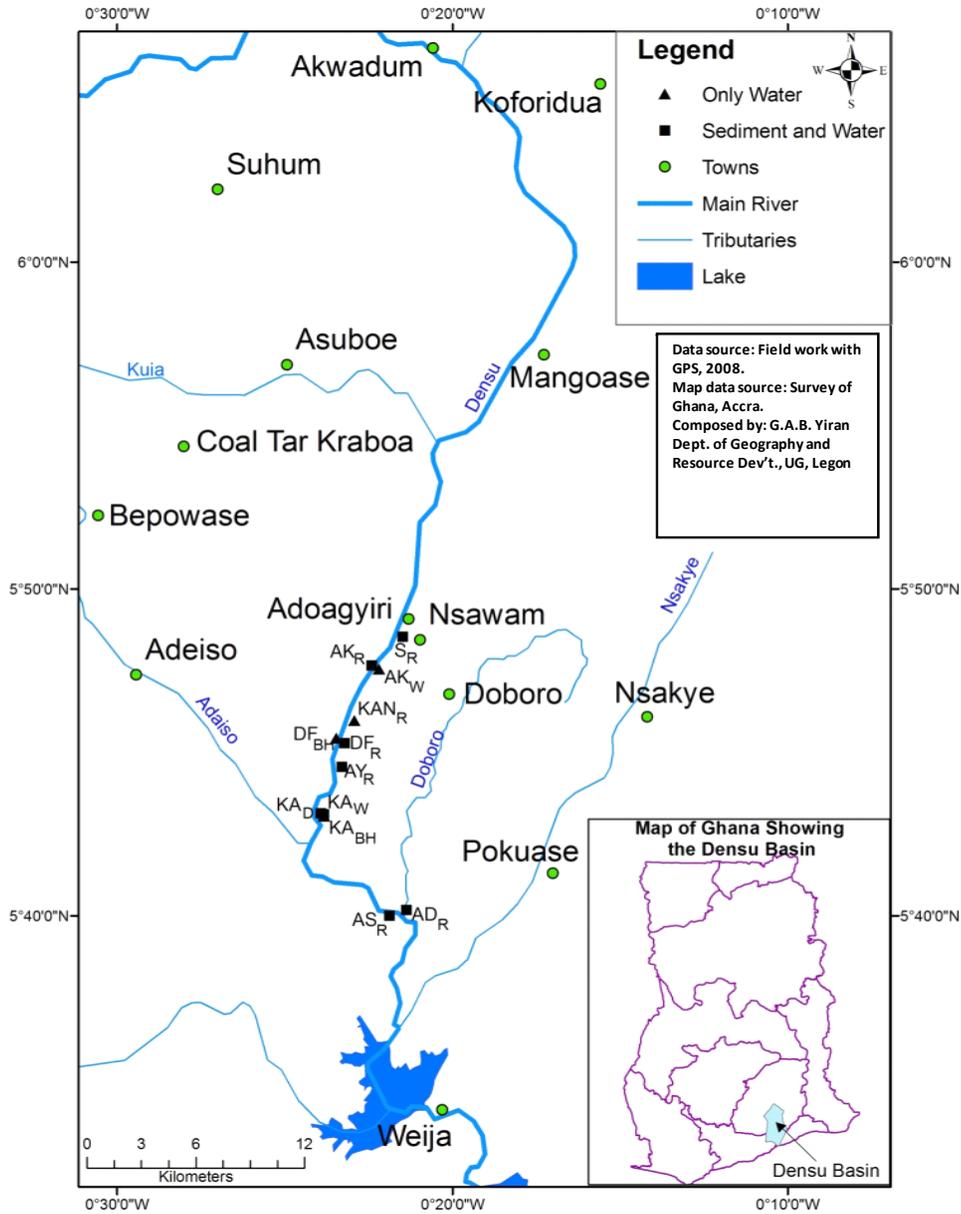


Fig. 2: A map of the Densu basin showing Sampling points along the Densu River

Table 2: Mean elemental concentrations in the water samples

ID	Fe (mg/L)	Mn (mg/L)	Zn (mg/L)	Alk (mg/L)
S _R	1.660	0.162	0.009	152
AK _W	6.090	0.039	0.021	60
AK _{S-R}	3.200	0.661	0.019	146
KAN _R	1.810	0.165	0.008	142
DF _R	1.940	0.174	*	258
DF _{BH}	0.124	0.144	0.015	280
AY _R	1.850	0.176	*	142
KA _W	1.950	0.183	*	138
KA _D	1.690	0.253	0.006	142
KA _{BH}	*	1.070	*	136
AS _R	1.590	0.183	*	130
AD _R	1.670	0.169	0.005	124

Alk: Alkalinity (by strong acid titration method); *: Not detected

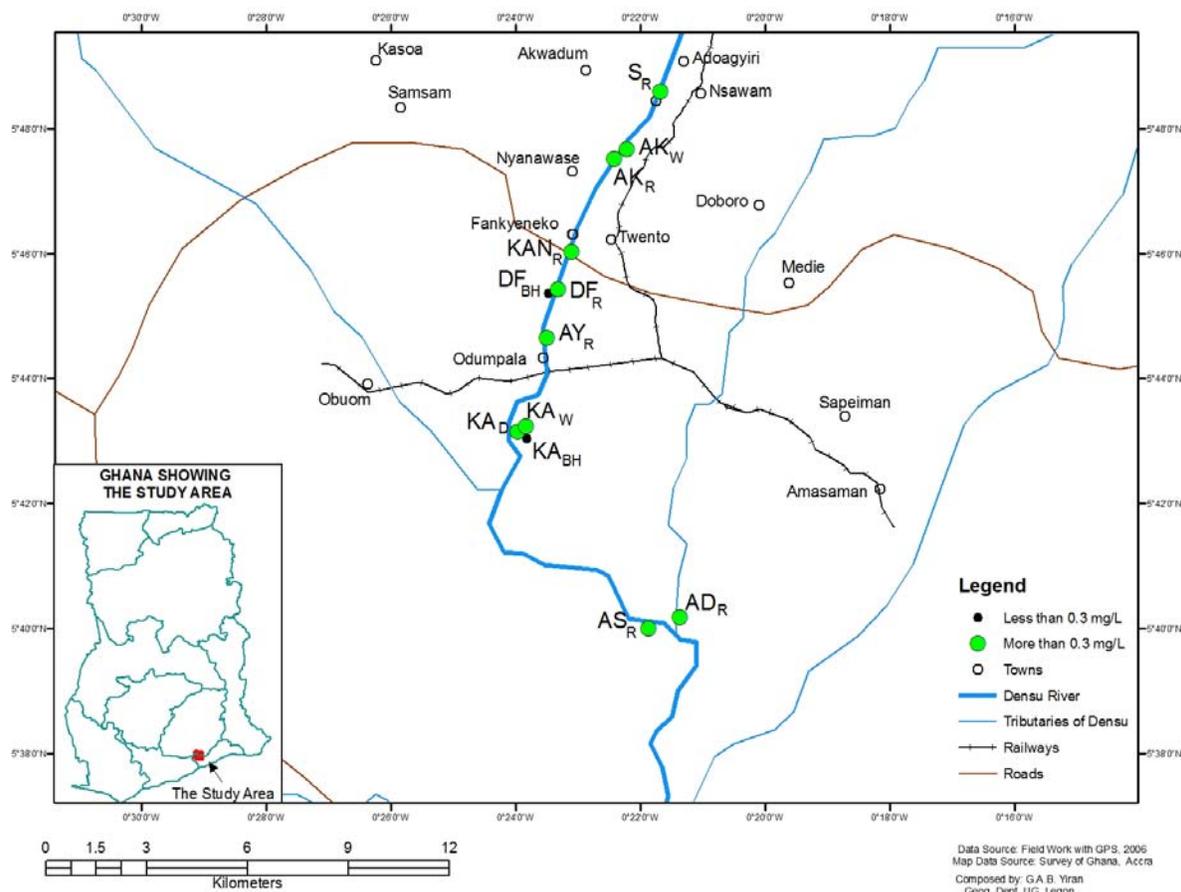


Fig. 3: A map of a section of the Densu basin showing the levels of Fe at the sampled points along the Densu River

Table 3: Mean concentrations in the Sediment samples

ID	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)
S	21.6	15,900	794	46.5
AK	46.5	47,800	1153	108.0
KAN	12.6	23,900	610	29.3
DF	14.5	16,000	171	31.9
AY	15.3	17,100	143	6.5
KA _W	30.1	33,800	1488	89.0
KA _D	6.0	42,400	165	7.6
AS	23.0	25,900	421	54.3
AD	15.3	11,200	291	10.0

Institute of Standards and Technology, USA, and NIVA SLP 0838 PROVE I from Norway were used for the validation of the analytical results.

RESULTS AND DISCUSSION

A summary of the results of the *in-situ* measurements and the trace element concentrations in the sampled water and sediment of River Densu are given in Table 1-3.

The concentrations of Cd, Cu, Hg and Ni were below their respective detection limits for the analytical method used. Table 4 shows for the detection limits.

Table 4: Detection limits of the Instrumentation

Elements	Water samples (mg/L)	Sediment samples (mg/kg)
Cd	0.002	0.002
Cu	0.02	0.02
Fe	0.01	0.01
Hg	0.02 µg /L	0.02 µg/kg
Mn	0.005	0.005
Ni	0.01	0.01
Zn	0.005	0.005
NO ₃ -N	0.005	0.005

Physico-chemical parameters: From Table 1, the pH of the river ranged from 6.55-7.33 with a mean of 6.71 and

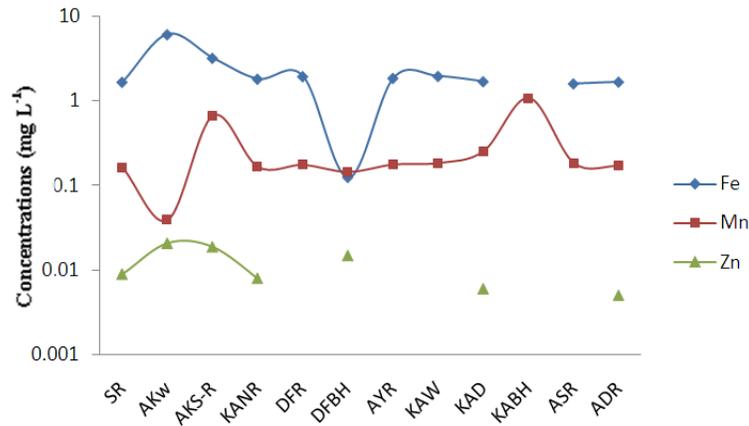


Fig. 4: Mean concentrations of Fe, Mn and Zn in water samples at the sampling sites

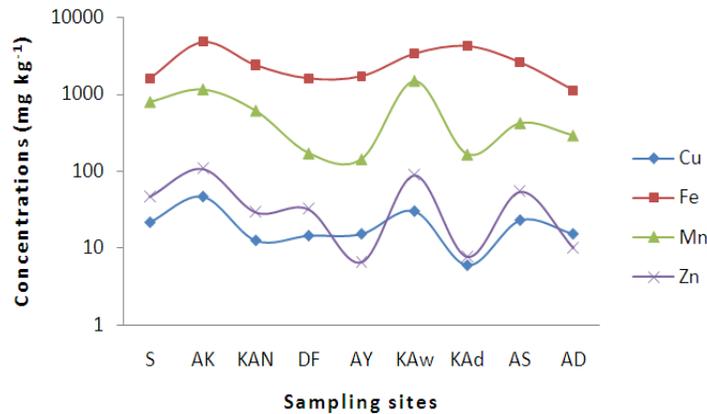


Fig. 5: Mean concentrations of Cu, Fe, Mn and Zn in sediment samples at the sampling sites

a standard deviation of 0.36. In general, the Densu River can be said to be neutral. The range was within the 6.5-8.5 stipulated for drinking and domestic purposes by the World Health Organisation (WHO, 2006). The pH obtained was also within the range 6-9 set by the EU for fisheries and aquatic life (Chapman, 1996). Thus, the pH of the river would not adversely affect its use for domestic and recreational purposes. The pH range obtained compares to those from earlier works conducted on the river (Biney, 1990; Karikari and Ansa-Asare, 2006). As expected, the salinity of the river (Table 1) was insignificant.

Electrical conductivity (EC) values of the river ranged from 150.3-223.0 $\mu\text{S}/\text{cm}$, with a mean value of $183 \pm 7 \mu\text{S}/\text{cm}$. Kojo Ashong (KA), located downstream recorded the highest conductivity of 223.0 $\mu\text{S}/\text{cm}$. The electrical conductivity of a river is generally lowest at the source of its catchment and leaches ions from the soils and also picks up organic material from biota and its detritus as it flows (Ferrari, 1989). The average electrical conductivity value of typically unpolluted rivers is

approximately 350 $\mu\text{S}/\text{cm}$ (Koning and Roos, 1999). This suggests that the electrical conductivity of the river falls within the acceptable limit. The Total Dissolved Solids (TDS) ranged from 67.1-113.0 mg/L. The correlation coefficient for the EC and TDS values (Table 1) is 0.99 which implies that the presence of the total dissolved solids is a major contributing factor to the conductivity of the river. The TDS values were below the WHO guideline value of 1000 mg/L. MacCutcheon *et al.* (1983) have indicated that, generally, the palatability of water with TDS level less than 600 mg/L is considered to be good whereas water with TDS level greater than 1200 mg/L gets increasingly unpalatable.

Trace metal concentration in water samples: The results of trace metal analysis in the water samples are presented in Table 2. The mean values for all the elements at all the sampling sites of the river were below the WHO maximum guideline values for the respective elements in drinking water, except for Fe and Mn. Figure 3 shows the sampling locations indicating the different levels of Fe

concentrations. The mean concentrations of Fe, Mn and Zn at the various sampled sites are indicated in Fig. 4. The levels of Fe, which were above the WHO guideline maximum value of 0.3 mg/L for drinking water, could be attributed to the weathering of the rocks underlying the basin. At Akraman (AK) the mean of Mn was above the WHO maximum guideline value of 0.4 mg/L for drinking water. This was at a confluence where a tributary joins the Densu River.

The Zn levels were below the Department of Water Affairs and Forestry (DWAf) of South Africa water quality guideline value of 20 mg/L for livestock watering and 1 mg/L for irrigation, but above 2 µg/L set for aquatic ecosystem (DWAf, 1998). The Zn levels could have chronic effects on aquatic life. The Fe levels in the river water were below the DWAf guideline value of 10 mg/L for livestock watering and 5 mg/L for irrigation. The Mn levels were below the DWAf guideline value of 10 mg/L set for livestock watering. However, the Mn levels were above the DWAf guideline value of 0.02 mg/L for irrigation.

Trace metal concentration in sediment samples: The results of trace metal analysis in the sediment samples are presented in Table 3. The concentrations of the Cd, Hg and Ni in the sediment samples were below their respective detection limits for the analytical method used.

Cu levels ranged from 6.0-46.5 mg/kg with the lowest at Kojo Ashong (KA) and the highest at Akraman (AK). These levels could be attributed to corrosion of copper pipes dumped in the river, and runoff from the use of copper as fungicides and pesticides in the treatment of the soils.

The mean concentrations of Fe ranged from 1.12-4.78 g/kg with the highest at AK and the lowest at AD. Also, the levels of Mn ranged from 143-1488 mg/kg with the highest at KA and the lowest at AY. The sources could be the rocks underlying the basin, paints, dyes, and ceramics dumped in the river. The mean concentrations of Cu, Fe, Mn and Zn are indicated in Fig. 5.

Enrichment factor (EF) computation was used to ascertain the anthropogenic source contribution to the elemental contents of the sediment samples. For the EF, Cu was used as a reference element because the Cu content in the water samples was below the detection limit of the instrumentation. The table of abundance of chemical elements in the continental crust given by Taylor and McLennan (1985) was used.

The EF of an element A in a sediment sample is defined as:

$$EF = \frac{\left(\frac{A}{R}\right)_{\text{Sediment samples}}}{\left(\frac{A}{R}\right)_{\text{Crust}}}$$

Table 5: Enrichment factors obtained for Fe, Mn and Zn using Cu as the reference element

ID	Fe	Mn	Zn
S	0.72	2.13	1.69
AK	1.00	1.44	1.82
KAN	1.85	2.80	1.83
DF	1.08	0.68	1.73
AY	1.09	0.54	0.34
KA _w	0.69	1.59	1.00
KA _D	1.10	2.86	2.32
AS	0.72	1.10	0.51
AD	1.10	1.06	1.85

where R is the concentration of the reference element Cu, and A is the concentration of the element of interest.

The EF values obtained for Fe were within the range of 0.69-1.85 with a mean of 1.04, which depicts that there is no anthropogenic contribution to Fe in the soil sediment (Taylor and McLennan, 1985). But the levels of Fe in the water samples were found to be high according to the WHO standards. Thus Fe readily dissolves in the water. Mn values ranged from 0.54-2.86 with a mean of 1.58. High values of 2.13, 2.80 and 2.86 for Mn occurred at the sites S, KAN and KA_D, respectively and could be attributed to slight anthropogenic contributions (Table 5). The likely anthropogenic contributions could be coming from emissions from exhaust fumes of tractors and the pesticides used on the farms on the banks of the river. The EF values obtained for Zn were within the range of 0.34-2.32 with a mean of 1.45. With the exception of AY, AS and KA_w sites, the other sites had Zn values of above 1.60 and could be said to be due to some slight anthropogenic source contribution.

CONCLUSION

The study has provided information about the water quality status of the Densu River. The pH levels obtained were within the natural background level of 6.5-8.5. The TDS values ranged from 67.1 to 113.0 mg/L and were below the WHO recommended value of 1000 mg/L. The Electrical Conductivity values obtained were from 150.3 to 223.0 µS/cm and were below the acceptable value of 350 µS/cm for unpolluted river. The salinity values were generally insignificant.

Fe levels were found to be above the WHO standard for drinking water. The Fe levels may have adverse effects on the health of users of the water without treatment over a long period of time. Enrichment factor computation for the soil sediments revealed that there could be moderate anthropogenic contributions to the levels of Mn and Zn in the sediments. According to DWAf standards for aquatic ecosystem, livestock watering and irrigation, the river water is suitable for livestock watering considering the levels of Fe, Mn and Zn recorded. The levels of Fe and Zn were also below the DWAf guideline values for irrigation, but that of Mn were above.

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